



(12) **United States Patent**
Lin et al.

(10) **Patent No.:** **US 9,064,936 B2**
(45) **Date of Patent:** **Jun. 23, 2015**

(54) **SEMICONDUCTOR DEVICE AND METHOD OF FORMING A VERTICAL INTERCONNECT STRUCTURE FOR 3-D FO-WLCSP**

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(73) Assignee: **STATS ChipPAC, Ltd.**, Singapore (SG)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **13/832,333**

(22) Filed: **Mar. 15, 2013**

(65) **Prior Publication Data**

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Related U.S. Application Data

(60) Continuation-in-part of application No. 13/191,318, filed on Jul. 26, 2011, and a continuation-in-part of application No. 12/572,590, filed on Oct. 2, 2009, now Pat. No. 8,796,846, which is a division of application

(Continued)

(51) **Int. Cl.**
H01L 21/768 (2006.01)
H01L 23/522 (2006.01)

(Continued)

(52) **U.S. Cl.**
CPC **H01L 21/76877** (2013.01); **H01L 23/5226** (2013.01); **H01L 2224/03002** (2013.01); **H01L 2224/14104** (2013.01); **H01L 2224/76155** (2013.01); **H01L 23/3157** (2013.01); **H01L 23/49816** (2013.01); **H01L 23/49827** (2013.01);

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(58) **Field of Classification Search**

CPC H01L 21/76877; H01L 23/5226; H01L 23/3157; H01L 23/49816; H01L 23/49827; H01L 21/561; H01L 21/568; H01L 23/5389; H01L 23/552; H01L 21/6835; H01L 24/82; H01L 24/96; H01L 25/0655; H01L 25/0657; H01L 21/6836

See application file for complete search history.

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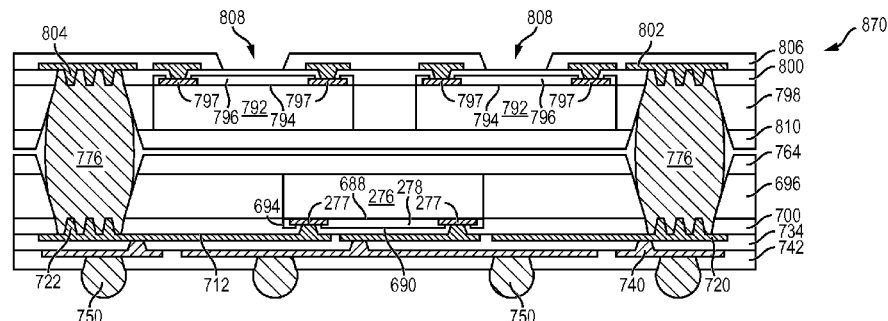
Primary Examiner — Long Pham

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(57) **ABSTRACT**

A semiconductor device has an encapsulant deposited over a first surface of the semiconductor die and around the semiconductor die. A first insulating layer is formed over a second surface of the semiconductor die opposite the first surface. A conductive layer is formed over the first insulating layer. An interconnect structure is formed through the encapsulant outside a footprint of the semiconductor die and electrically connected to the conductive layer. The first insulating layer includes an optically transparent or translucent material. The semiconductor die includes a sensor configured to receive an external stimulus passing through the first insulating layer. A second insulating layer is formed over the first surface of the semiconductor die. A conductive via is formed through the first insulating layer outside a footprint of the semiconductor die. A plurality of stacked semiconductor devices is electrically connected through the interconnect structure.

12 Claims, 47 Drawing Sheets



Related U.S. Application Data

No. 12/333,977, filed on Dec. 12, 2008, now Pat. No. 7,642,128, application No. 13/832,333, which is a continuation-in-part of application No. 13/326,128, filed on Dec. 14, 2011, now Pat. No. 8,592,992.

- (60) Provisional application No. 61/441,561, filed on Feb. 10, 2011, provisional application No. 61/444,914, filed on Feb. 21, 2011.

(51) **Int. Cl.**

H01L 23/31 (2006.01)
H01L 23/498 (2006.01)
H01L 21/56 (2006.01)
H01L 23/538 (2006.01)
H01L 23/552 (2006.01)
H01L 21/683 (2006.01)
H01L 25/065 (2006.01)
H01L 25/10 (2006.01)
H01L 23/00 (2006.01)

(52) **U.S. Cl.**

CPC **H01L 21/561** (2013.01); **H01L 21/568** (2013.01); **H01L 23/5389** (2013.01); **H01L 23/552** (2013.01); **H01L 24/16** (2013.01); **H01L 21/6835** (2013.01); **H01L 24/82** (2013.01); **H01L 24/96** (2013.01); **H01L 25/0655** (2013.01); **H01L 25/0657** (2013.01); **H01L 25/105** (2013.01); **H01L 2221/68345** (2013.01); **H01L 2221/68381** (2013.01); **H01L 2223/54426** (2013.01); **H01L 2224/03003** (2013.01); **H01L 2224/04105** (2013.01); **H01L 2224/0557** (2013.01); **H01L 2224/0613** (2013.01); **H01L 2224/12105** (2013.01); **H01L 2224/13014** (2013.01); **H01L 2224/13021** (2013.01); **H01L 2224/13025** (2013.01); **H01L 2224/131** (2013.01); **H01L 2224/13111** (2013.01); **H01L 2224/13113** (2013.01); **H01L 2224/13116** (2013.01); **H01L 2224/13124** (2013.01); **H01L 2224/13139** (2013.01); **H01L 2224/13144** (2013.01); **H01L 2224/13147** (2013.01); **H01L 2224/13155** (2013.01); **H01L 2224/16145** (2013.01); **H01L 2224/16237** (2013.01); **H01L 2224/16238** (2013.01); **H01L 2224/73253** (2013.01); **H01L 2224/81191** (2013.01); **H01L 2224/81193** (2013.01); **H01L 2224/82005** (2013.01); **H01L 2224/92** (2013.01); **H01L 2224/94** (2013.01); **H01L 2224/96** (2013.01); **H01L 2924/01004** (2013.01); **H01L 2924/01006** (2013.01); **H01L 2924/01013** (2013.01); **H01L 2924/01023** (2013.01); **H01L 2924/01024** (2013.01); **H01L 2924/01029** (2013.01); **H01L 2924/01033** (2013.01); **H01L 2924/01046** (2013.01); **H01L 2924/01047** (2013.01); **H01L 2924/01049** (2013.01); **H01L 2924/01072** (2013.01); **H01L 2924/01073** (2013.01); **H01L 2924/01074** (2013.01); **H01L 2924/01078** (2013.01); **H01L 2924/01079** (2013.01); **H01L 2924/01082** (2013.01); **H01L 2924/01322** (2013.01); **H01L 2924/014** (2013.01); **H01L 2924/09701**

(2013.01); **H01L 2924/13091** (2013.01); **H01L 2924/14** (2013.01); **H01L 2924/1433** (2013.01); **H01L 2924/15311** (2013.01); **H01L 2924/1532** (2013.01); **H01L 2924/15331** (2013.01); **H01L 2924/1815** (2013.01); **H01L 2924/18161** (2013.01); **H01L 2924/19041** (2013.01); **H01L 2924/19042** (2013.01); **H01L 2924/19043** (2013.01); **H01L 2924/30105** (2013.01); **H01L 2924/3025** (2013.01); **H01L 2225/06513** (2013.01); **H01L 2225/06541** (2013.01); **H01L 21/6836** (2013.01); **H01L 2221/68327** (2013.01); **H01L 2224/73267** (2013.01); **H01L 2225/06517** (2013.01); **H01L 2225/1035** (2013.01); **H01L 2225/1058** (2013.01); **H01L 24/97** (2013.01); **H01L 2224/48091** (2013.01); **H01L 2224/73265** (2013.01); **H01L 2224/16225** (2013.01); **H01L 24/13** (2013.01); **H01L 2224/0346** (2013.01); **H01L 2224/1132** (2013.01); **H01L 2224/11334** (2013.01); **H01L 2224/1146** (2013.01); **H01L 2224/81447** (2013.01); **H01L 2224/97** (2013.01); **H01L 2224/05571** (2013.01); **H01L 2224/05611** (2013.01); **H01L 2224/05624** (2013.01); **H01L 2224/05639** (2013.01); **H01L 2224/05644** (2013.01); **H01L 2224/05647** (2013.01); **H01L 2224/05655** (2013.01); **H01L 2924/18162** (2013.01); **H01L 2924/12041** (2013.01); **H01L 2924/1306** (2013.01)

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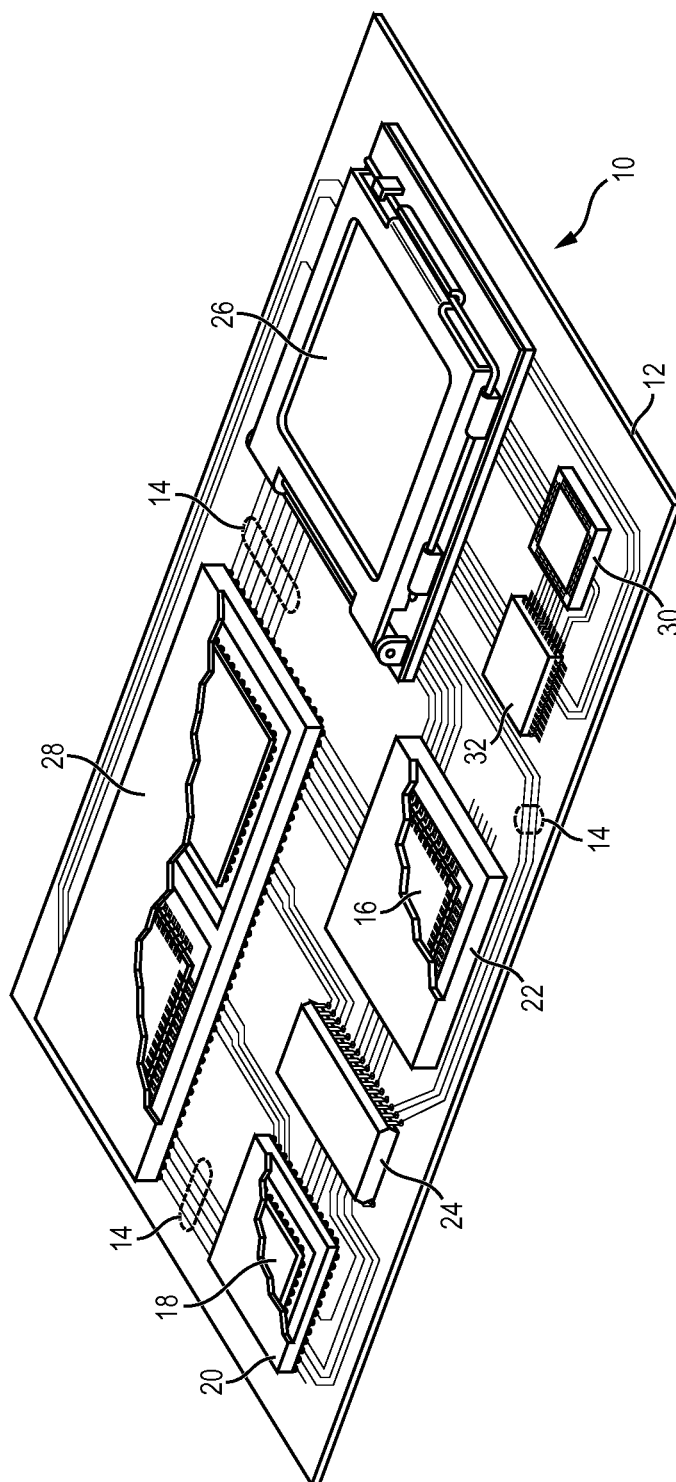


FIG. 1

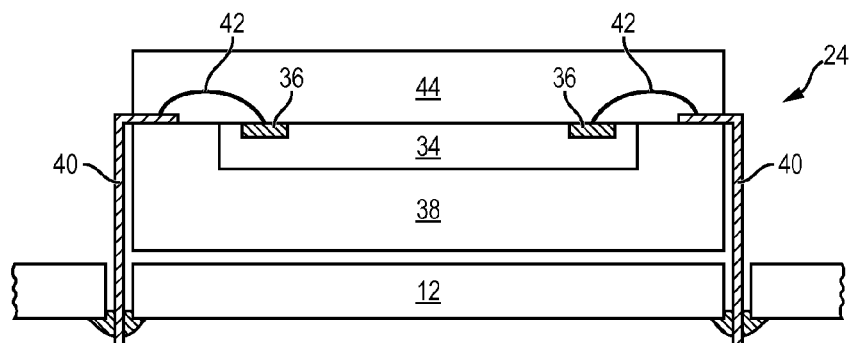


FIG. 2a

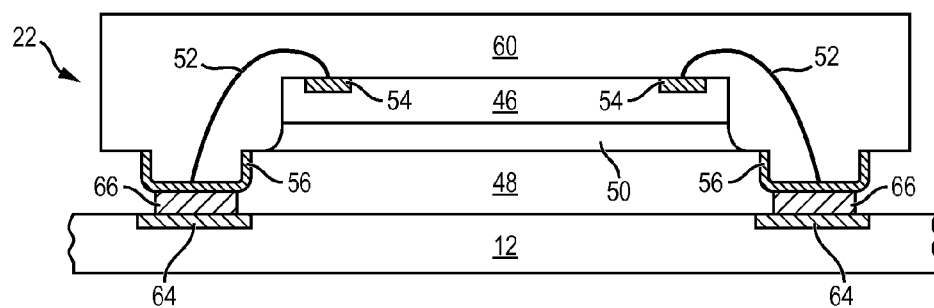


FIG. 2b

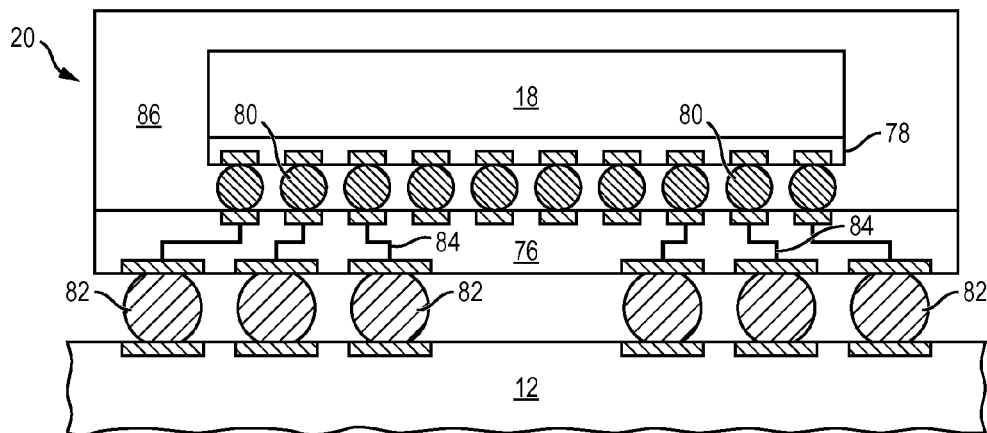


FIG. 2c

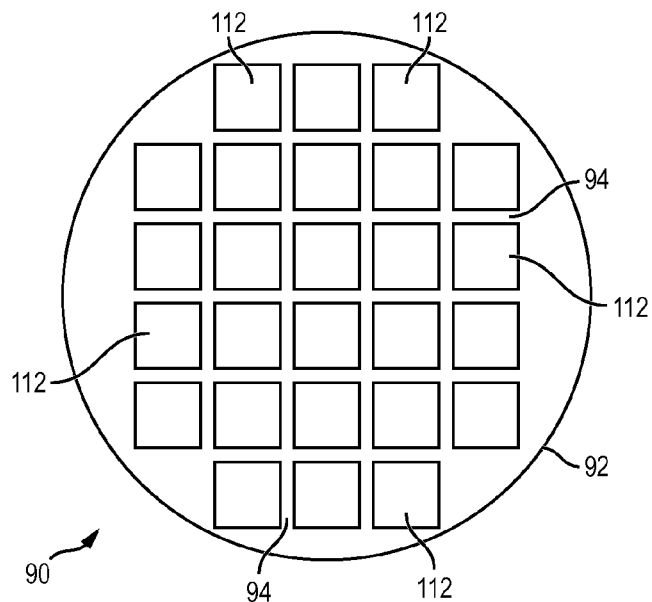


FIG. 3a

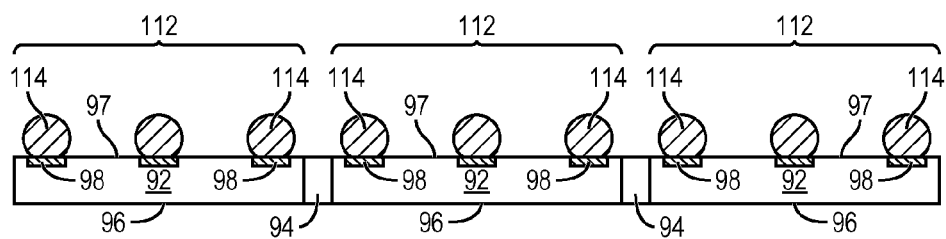


FIG. 3b

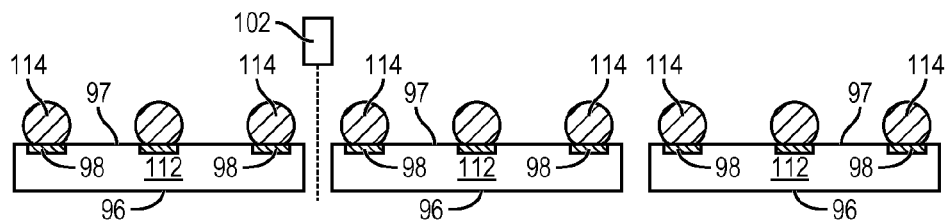


FIG. 3c

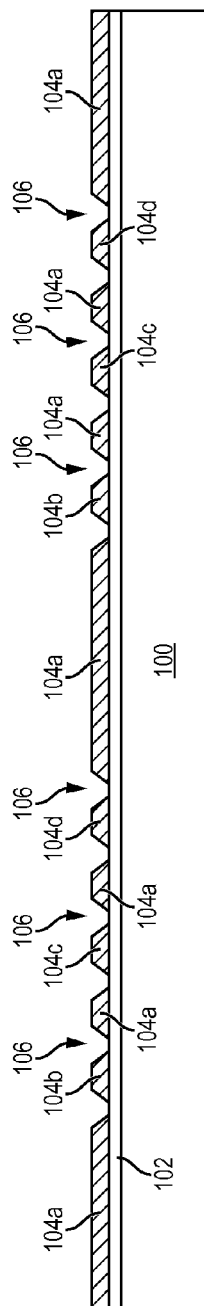


FIG. 4a

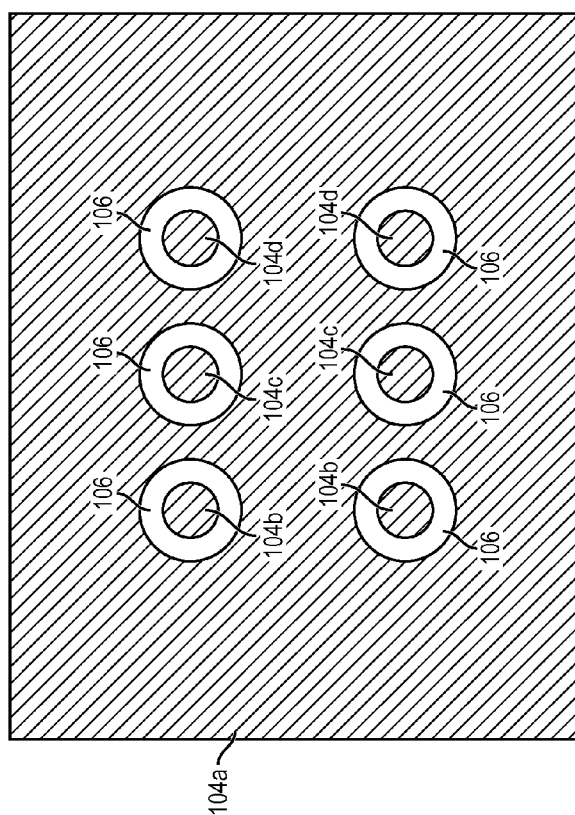


FIG. 4b

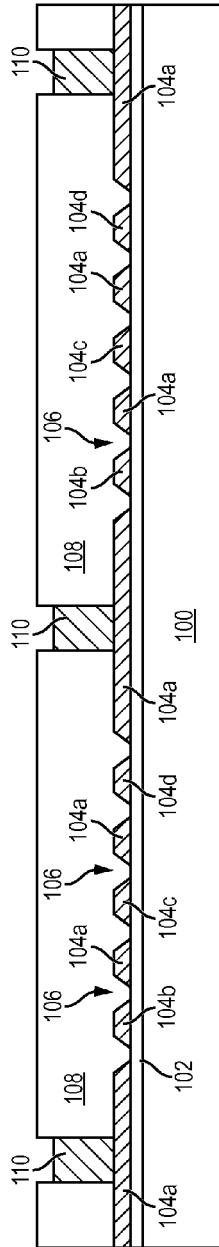


FIG. 4c

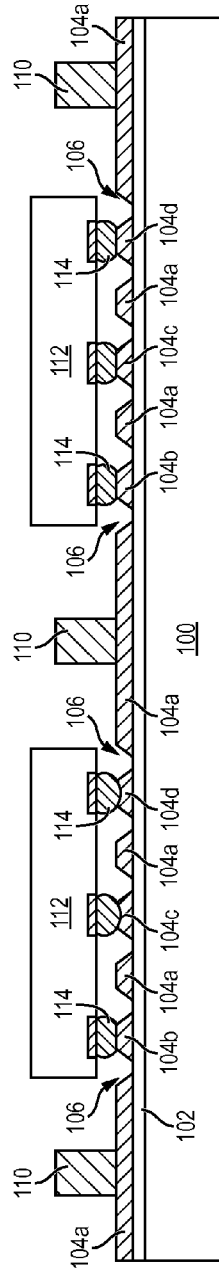


FIG. 4d

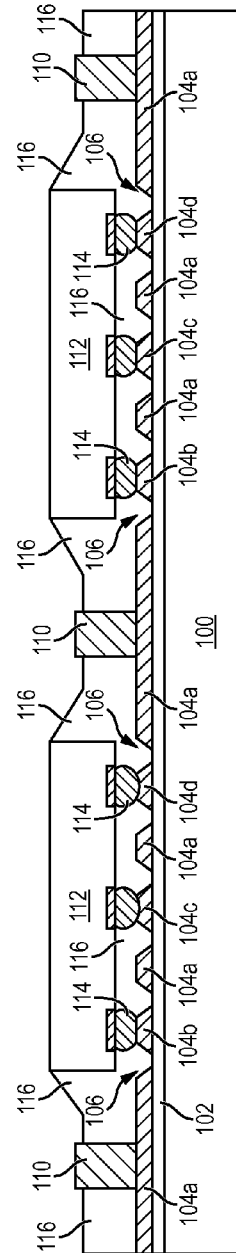


FIG. 4e

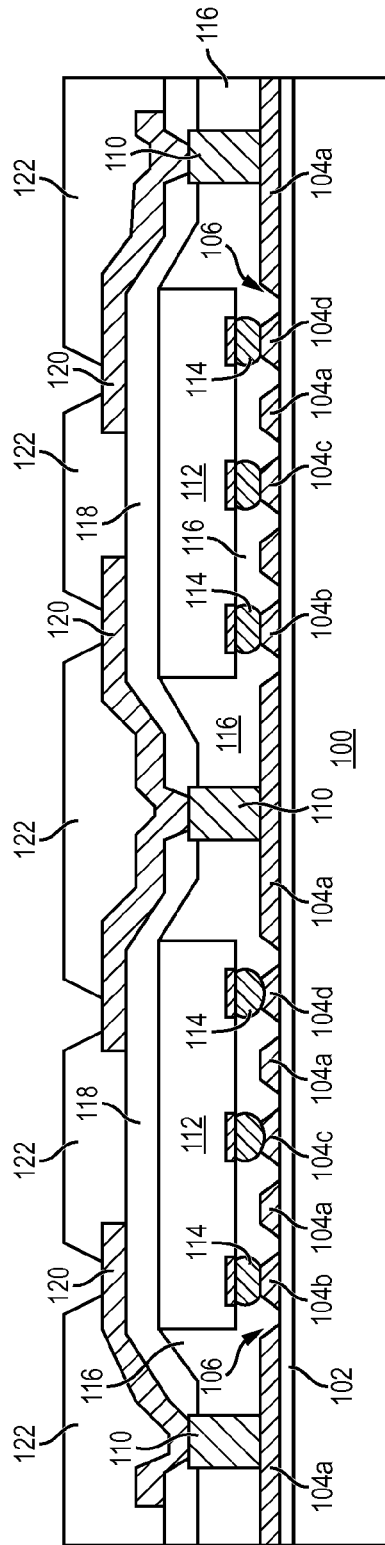


FIG. 4f

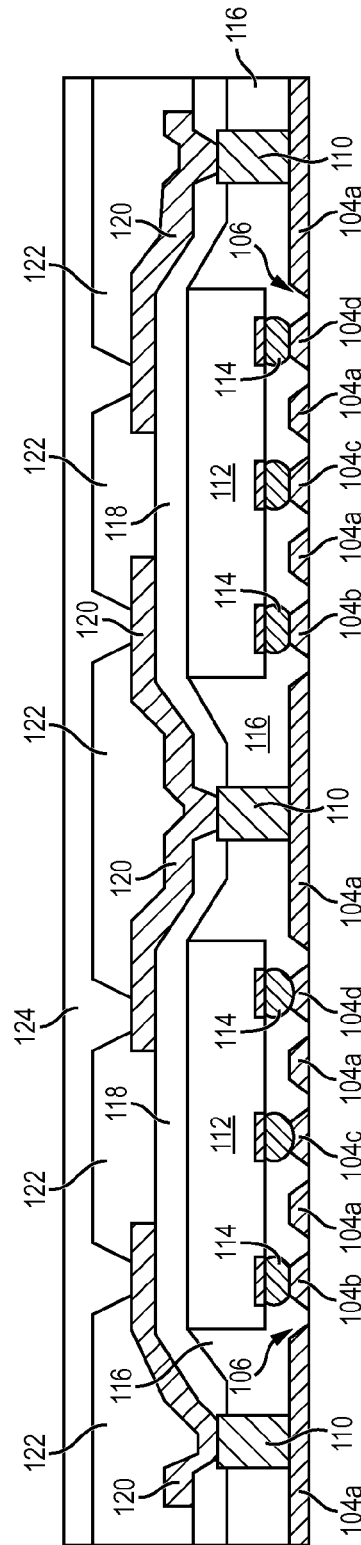


FIG. 4g

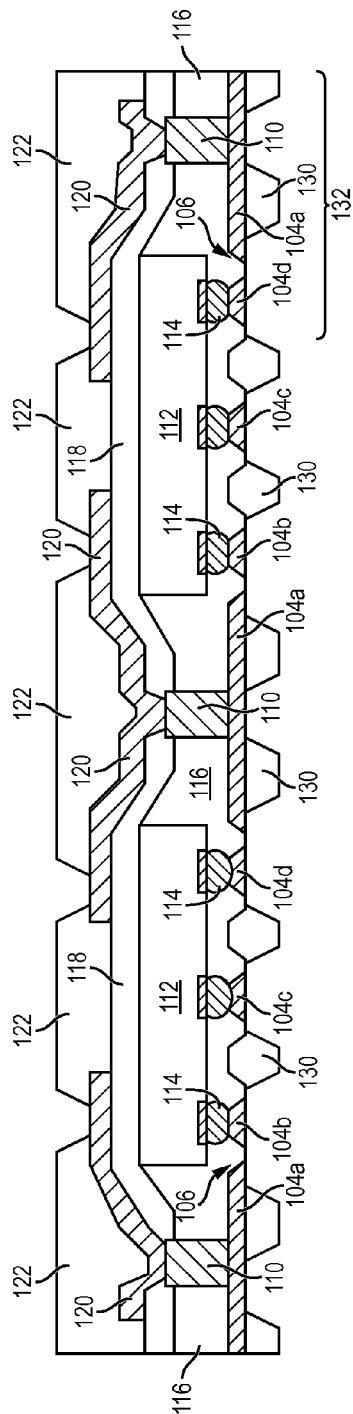


FIG. 4h

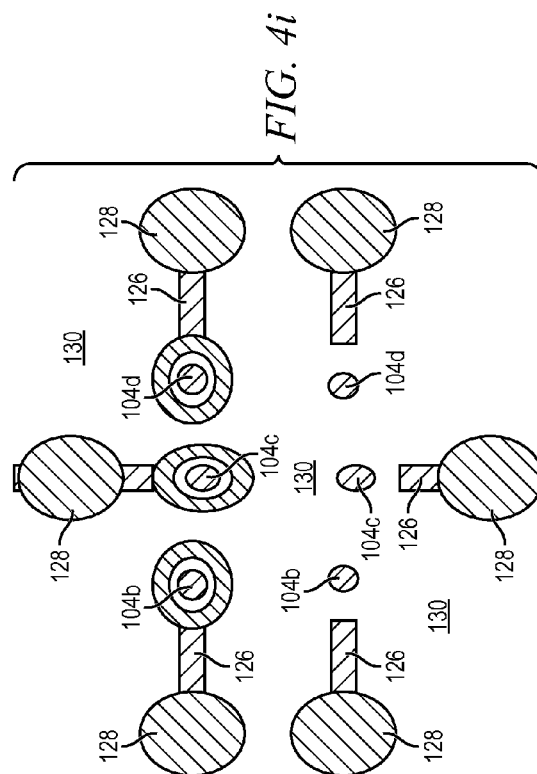


FIG. 4i

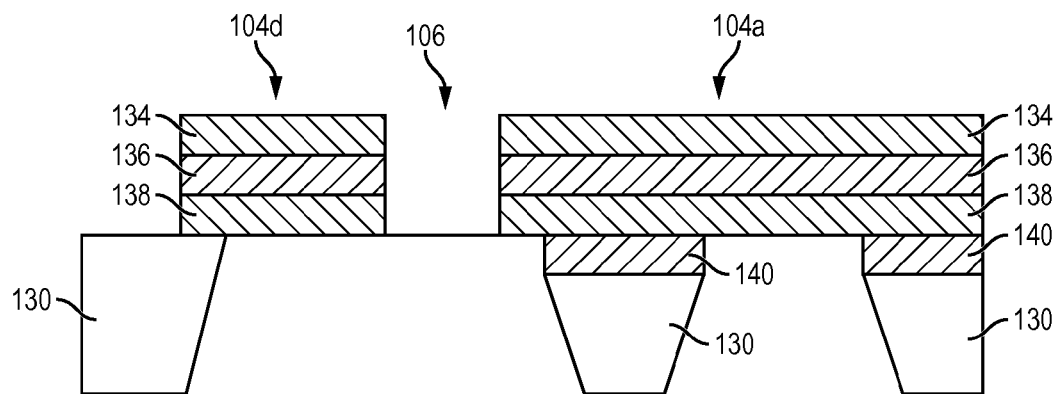


FIG. 4j

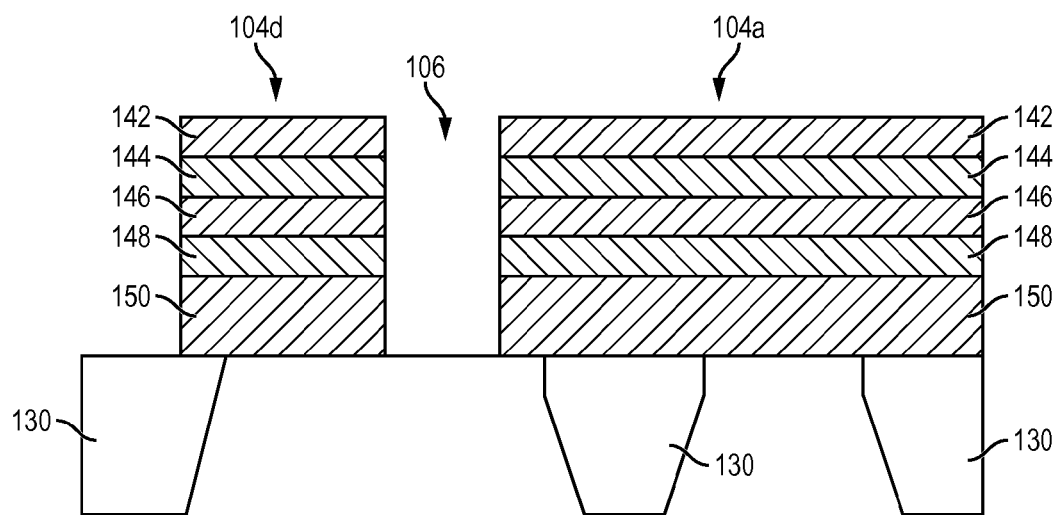


FIG. 4k

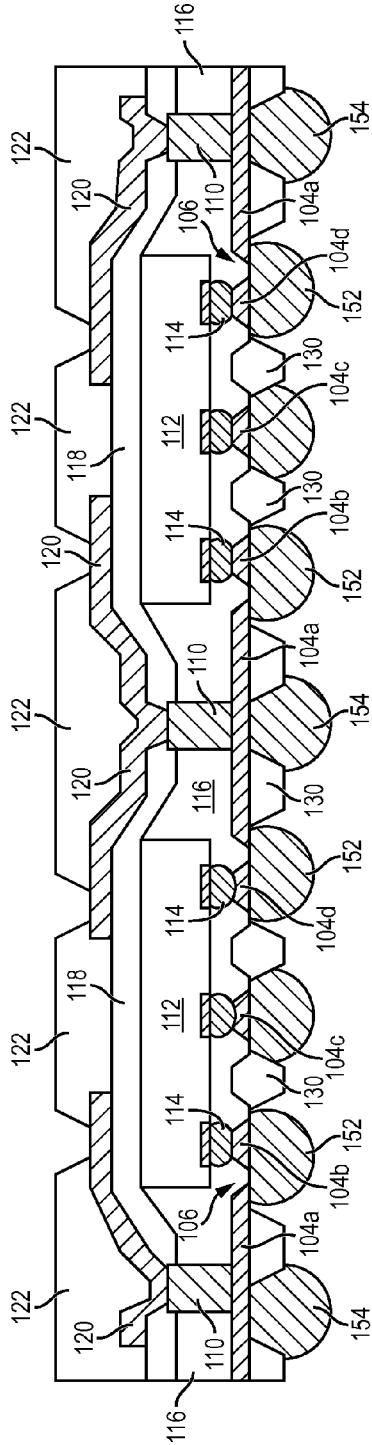


FIG. 5a

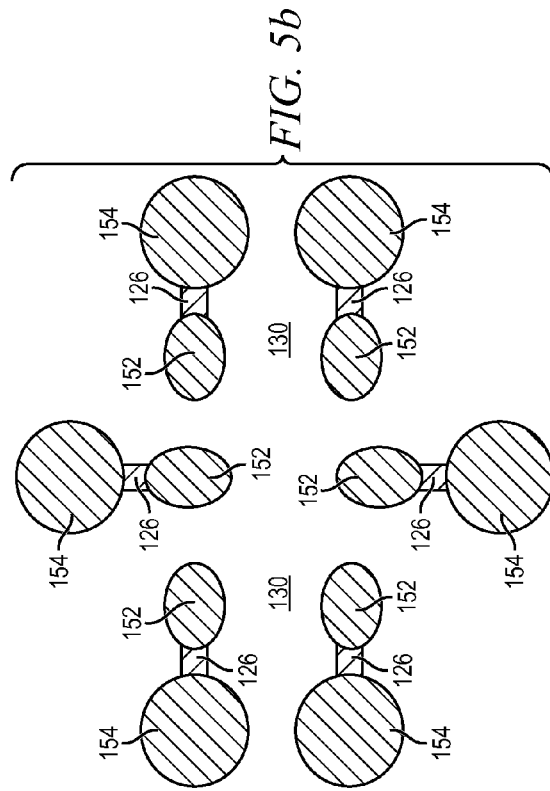


FIG. 5b

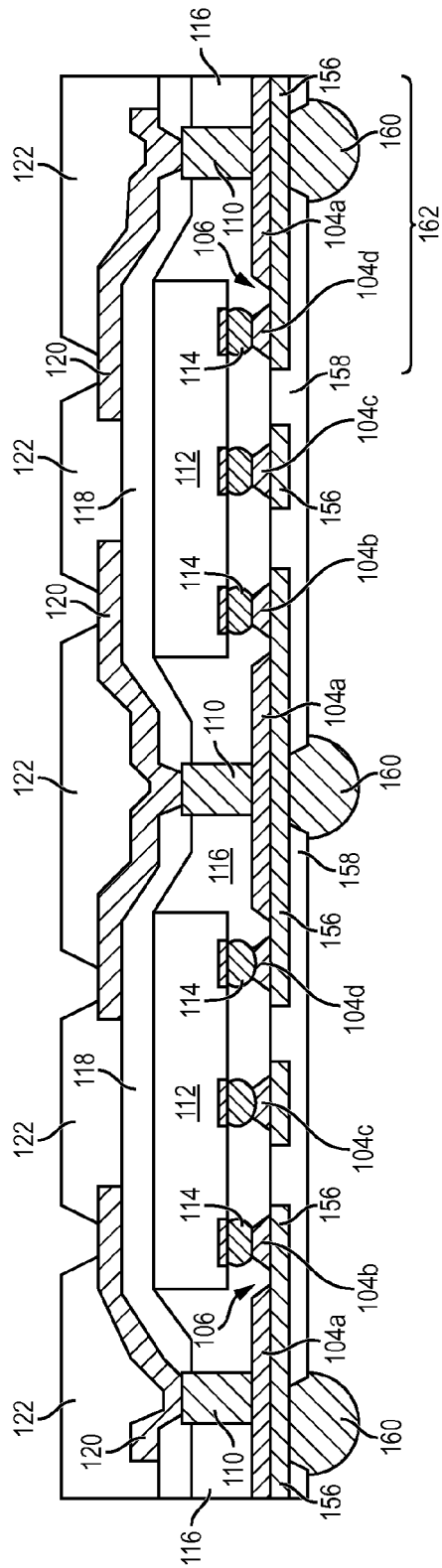


FIG. 6

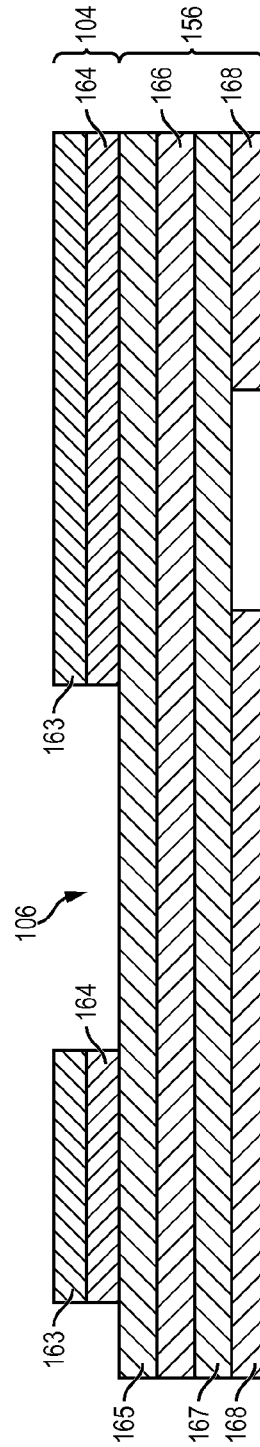


FIG. 7

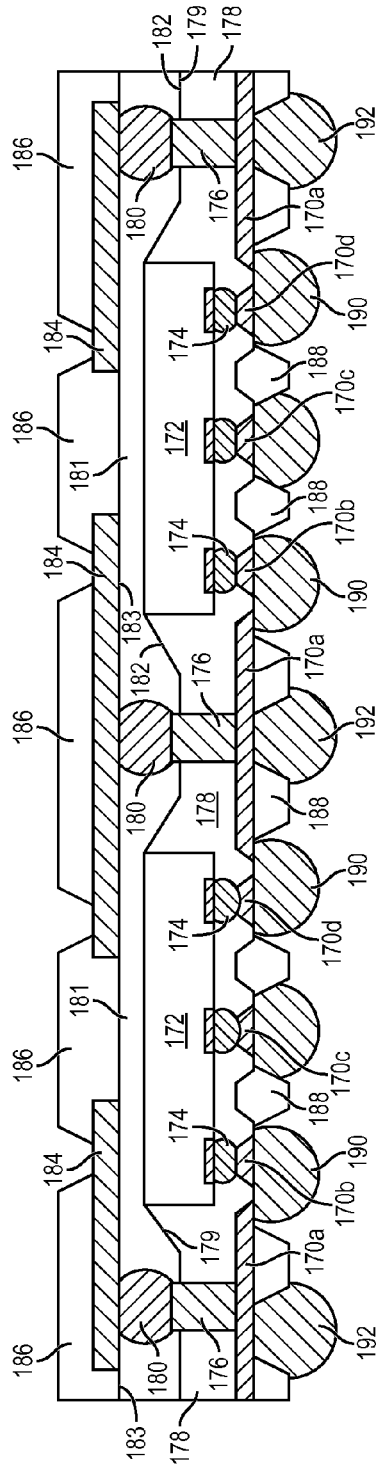


FIG. 8

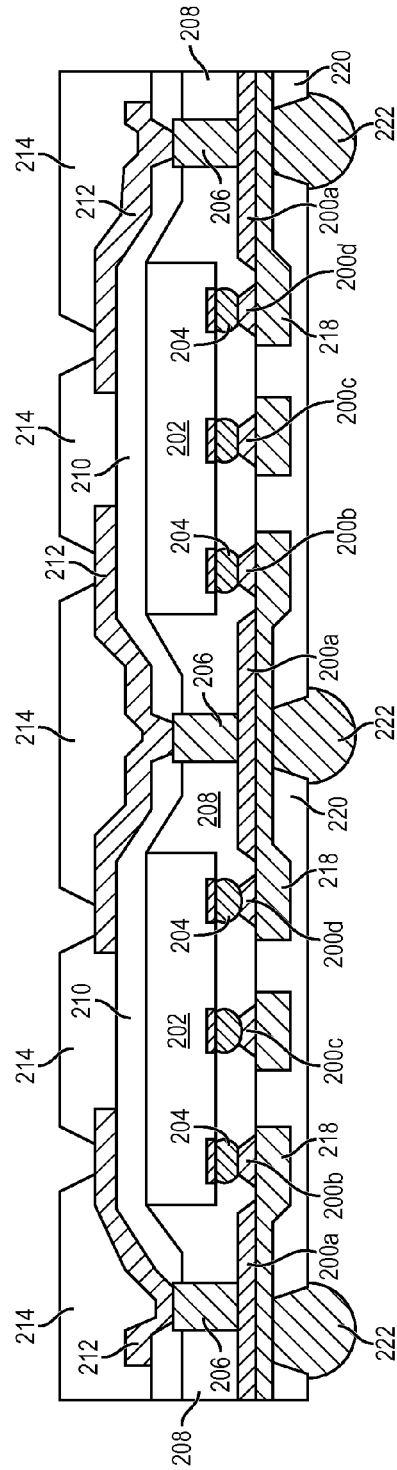


FIG. 9a

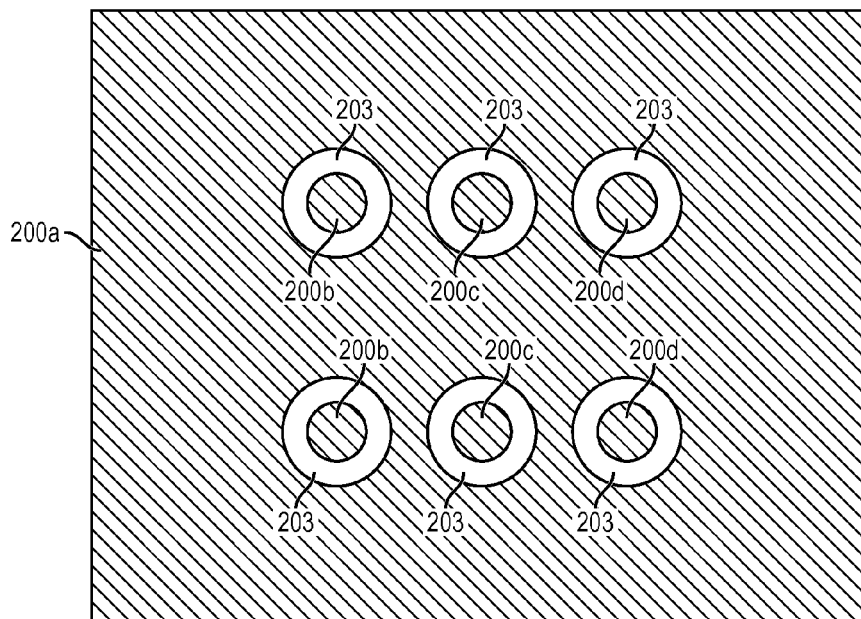
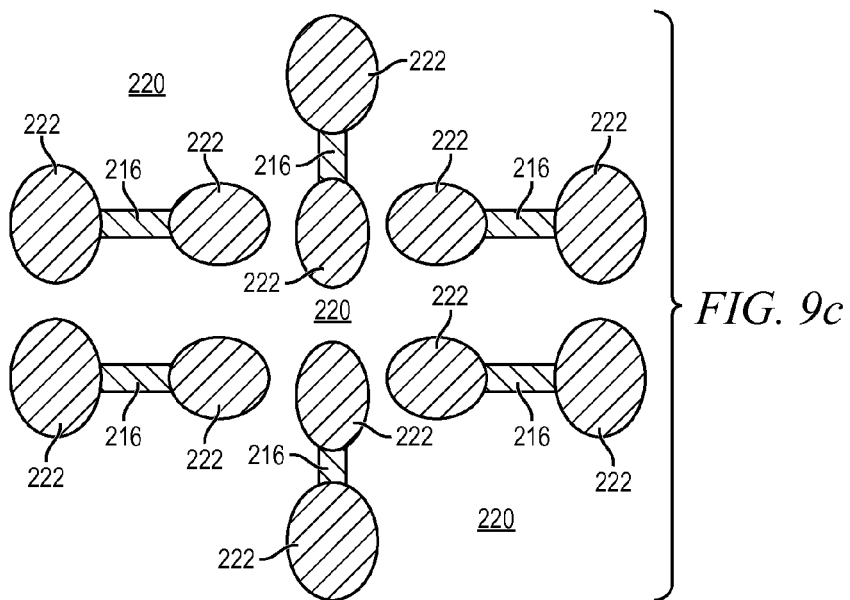


FIG. 9b



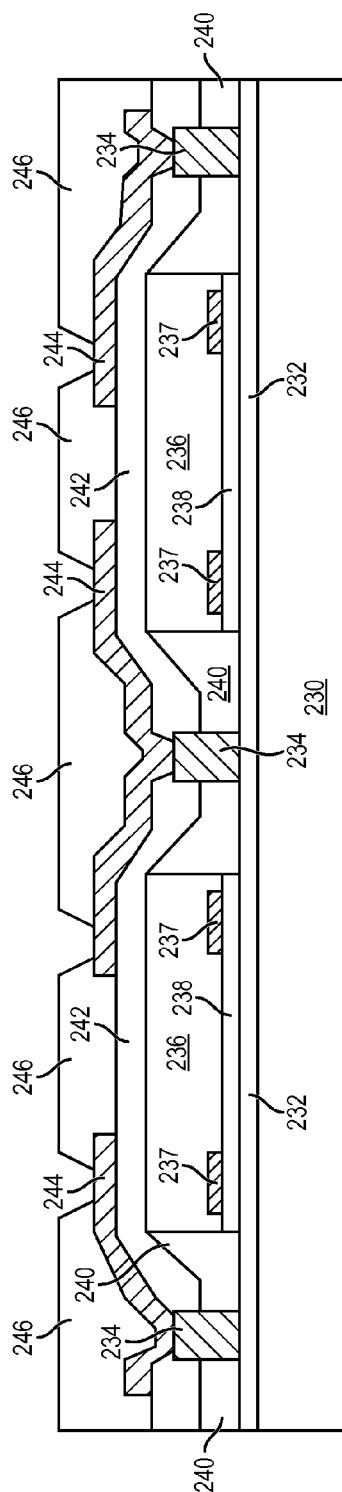


FIG. 10a

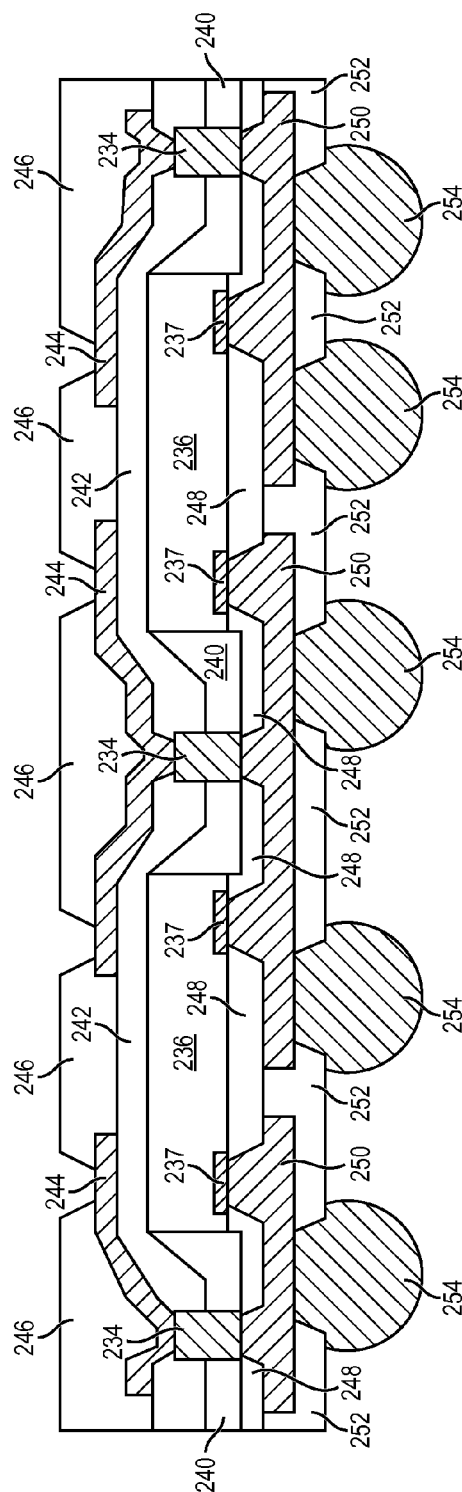


FIG. 10b

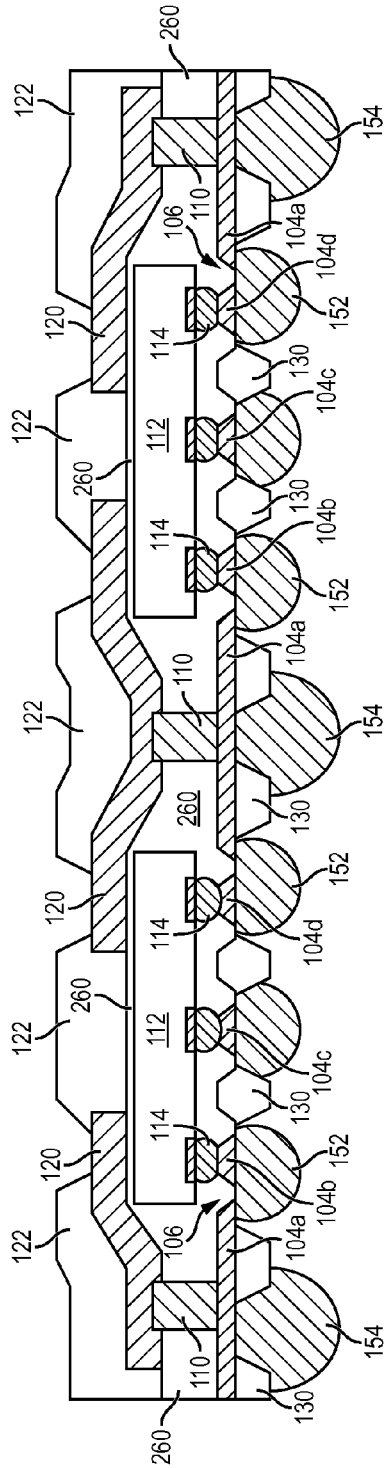


FIG. 11

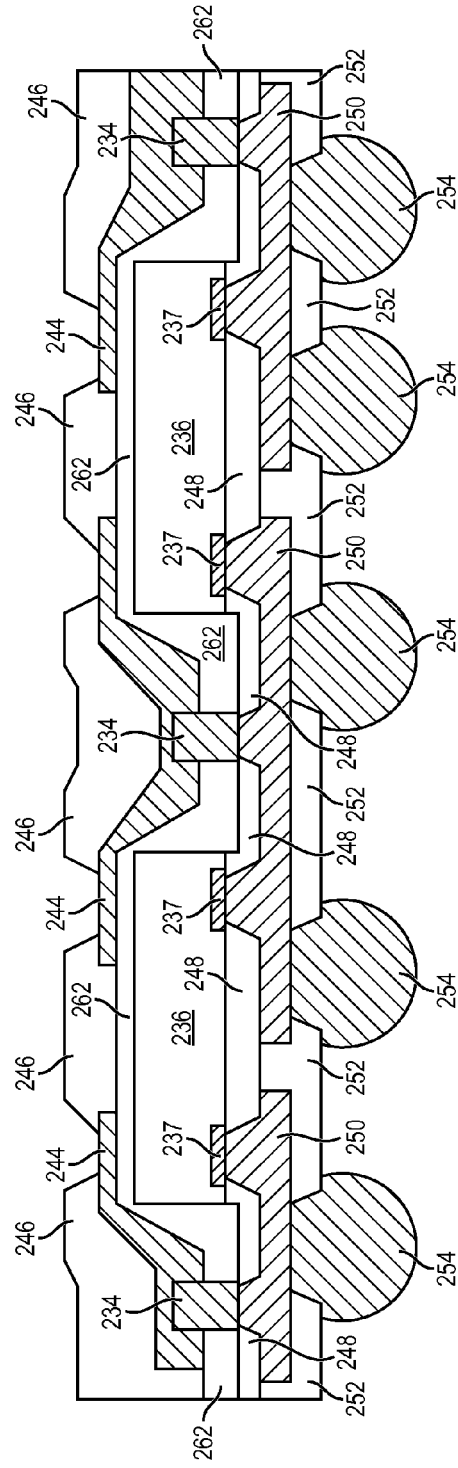


FIG. 12

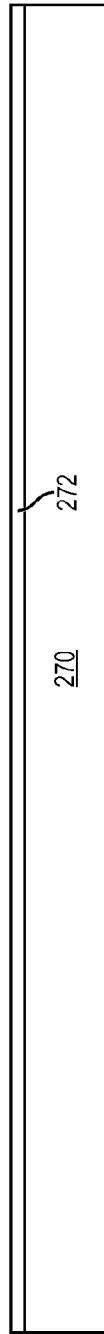


FIG. 13a

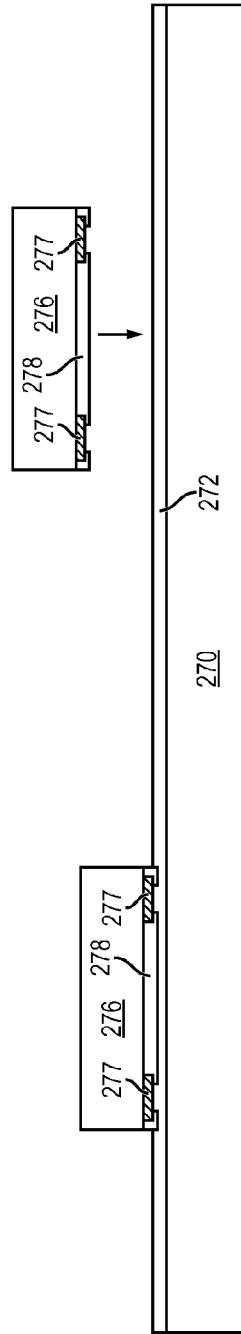


FIG. 13b

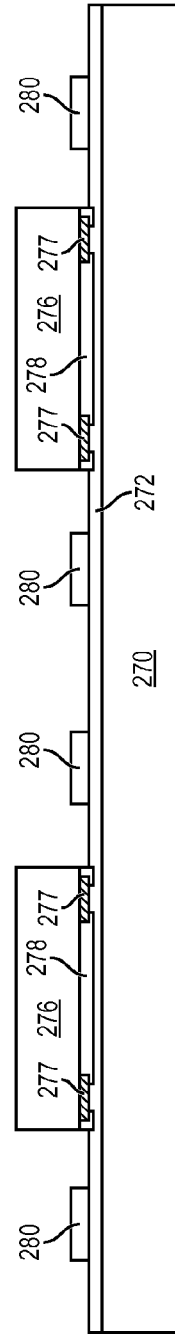


FIG. 13c

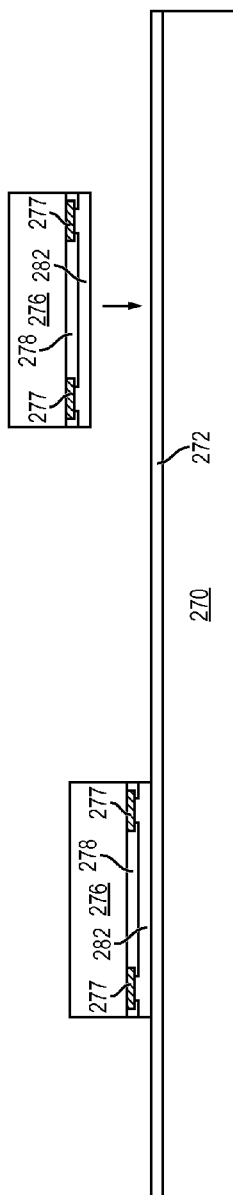


FIG. 13d

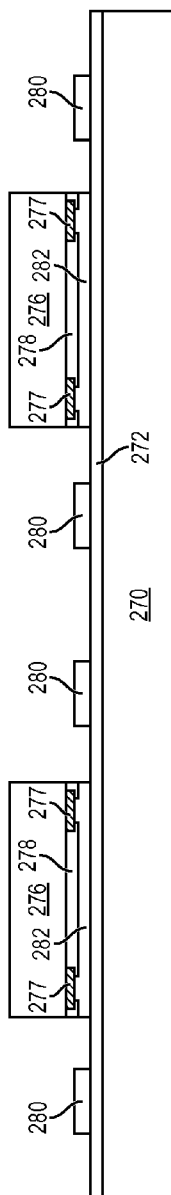


FIG. 13e

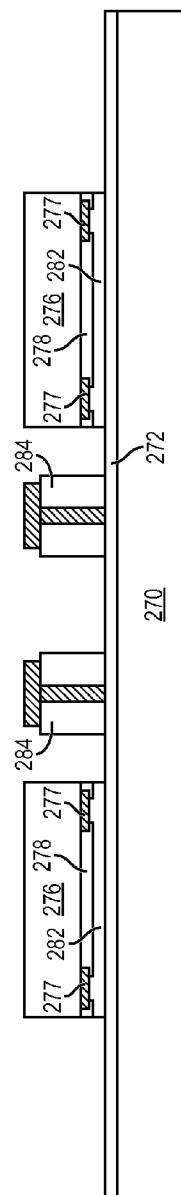


FIG. 13f

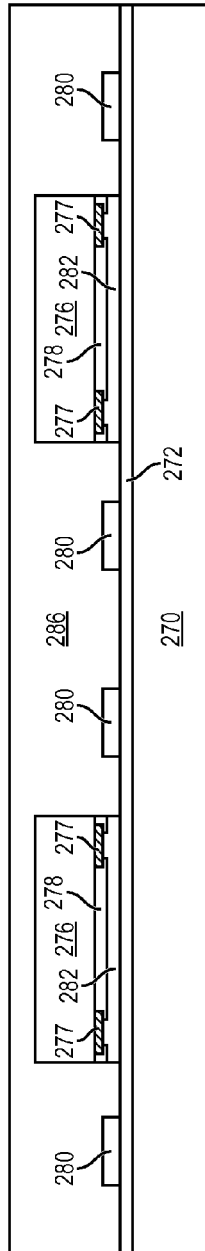


FIG. 13g

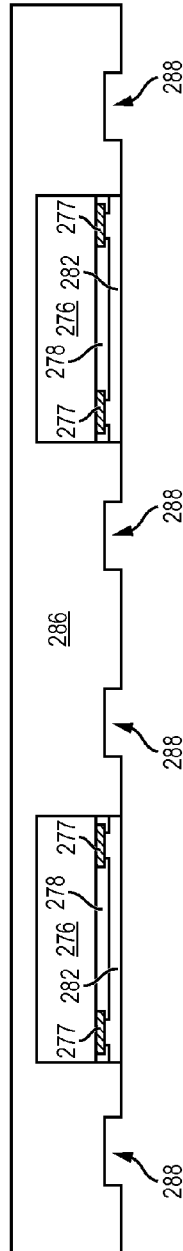


FIG. 13h

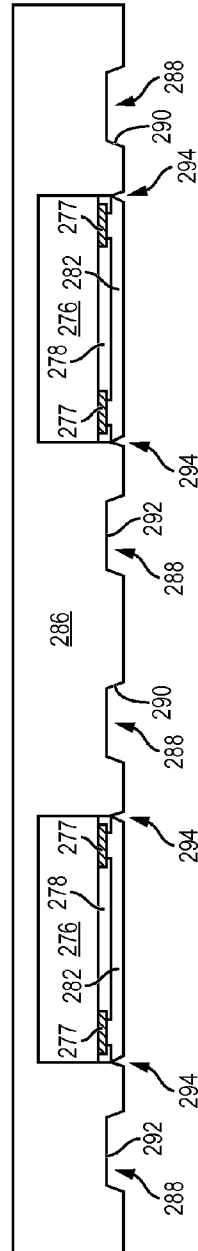


FIG. 13i

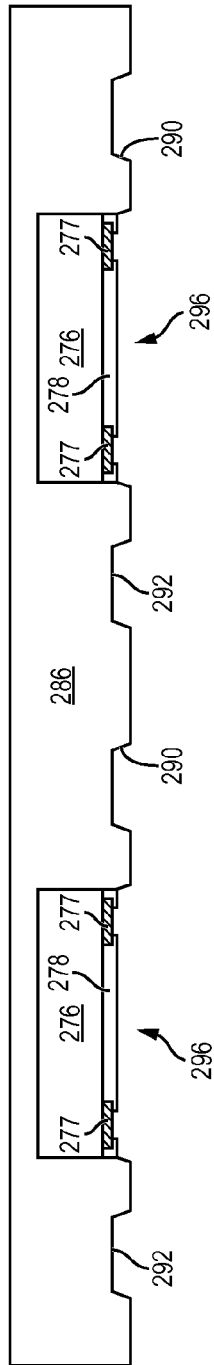


FIG. 13j

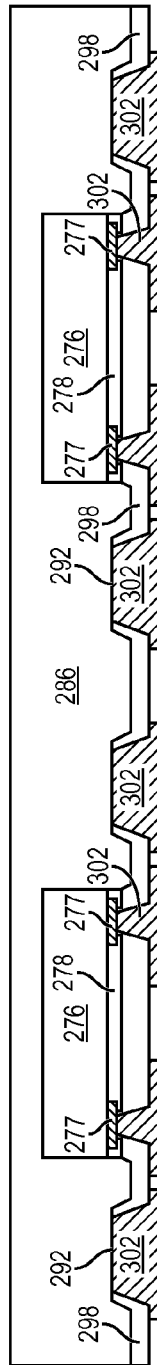


FIG. 13k

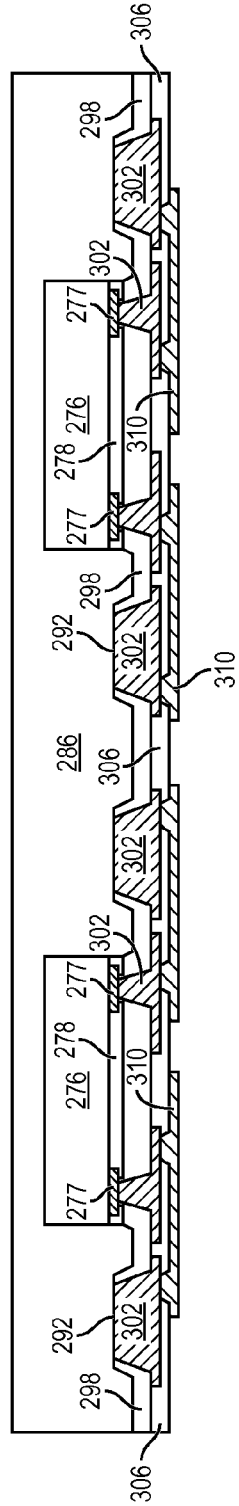


FIG. 13l

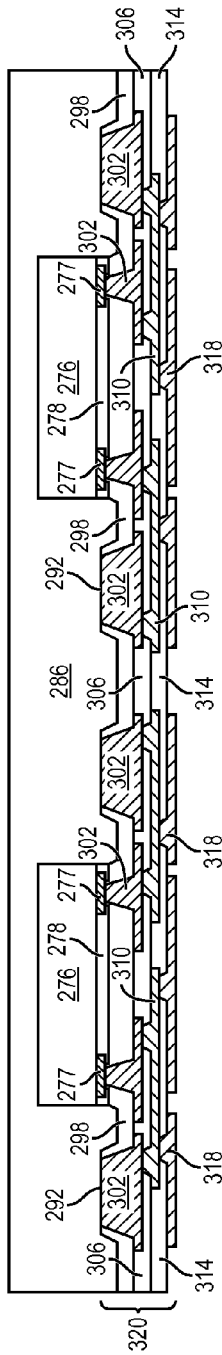


FIG. 13m

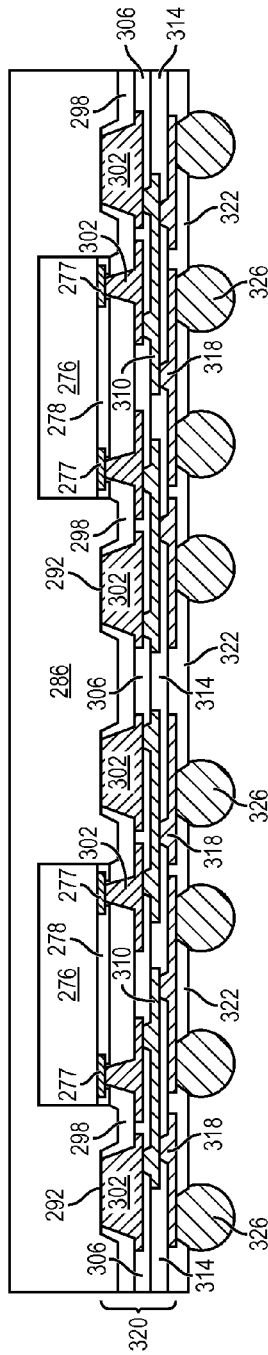


FIG. 13n

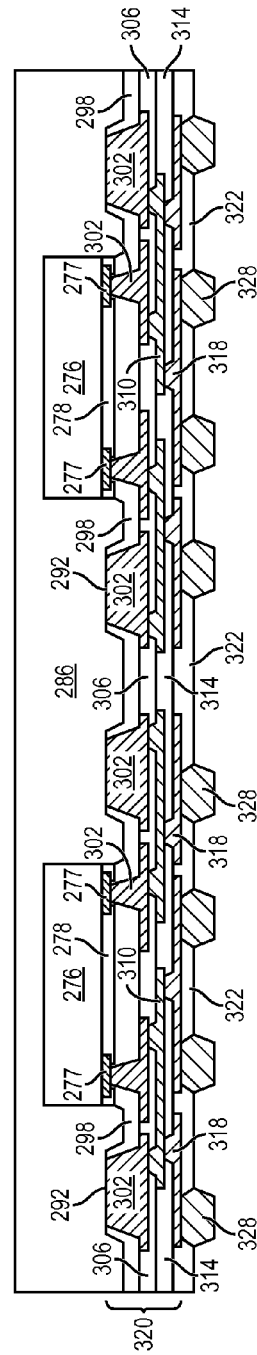


FIG. 13o

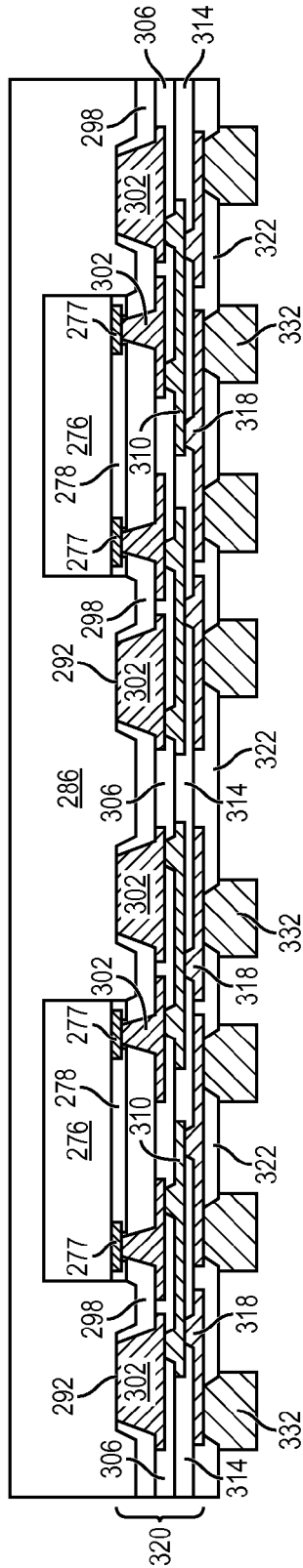


FIG. 13p

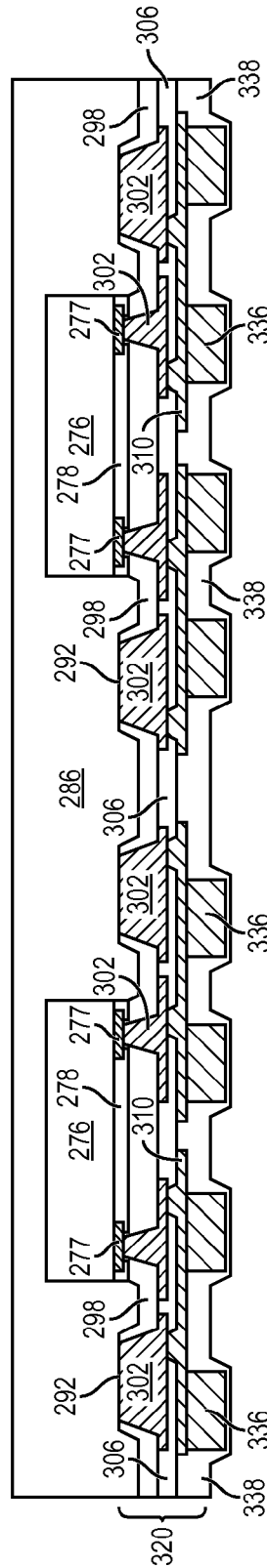


FIG. 13q

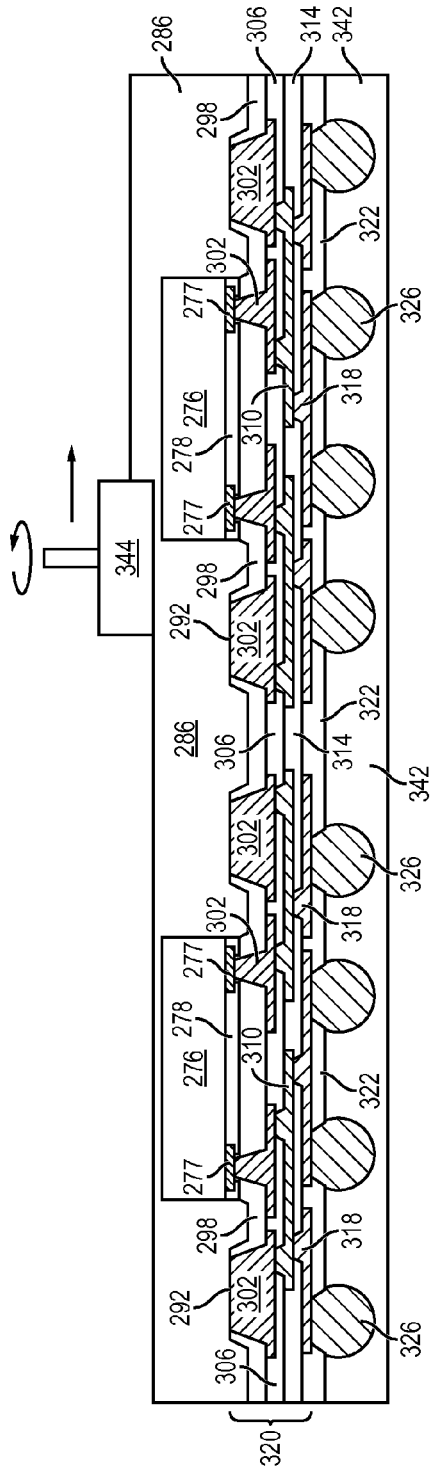


FIG. 13r

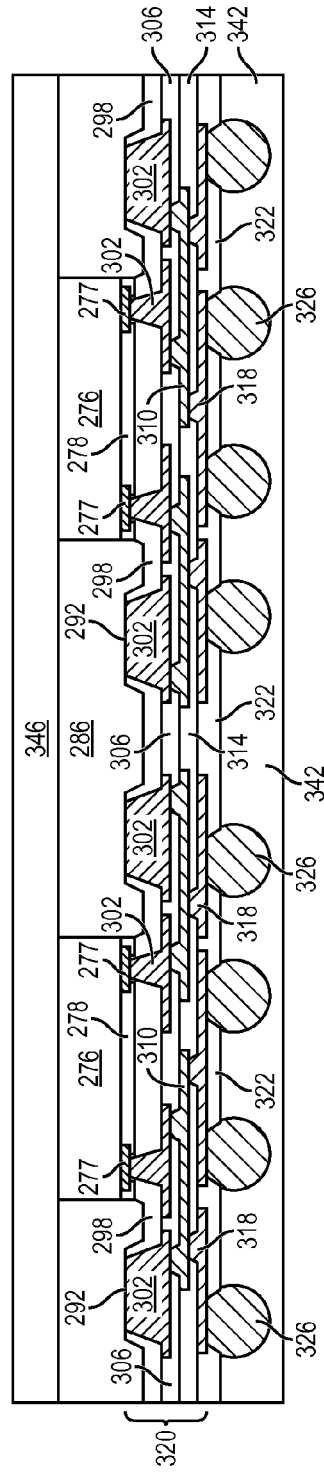


FIG. 13s

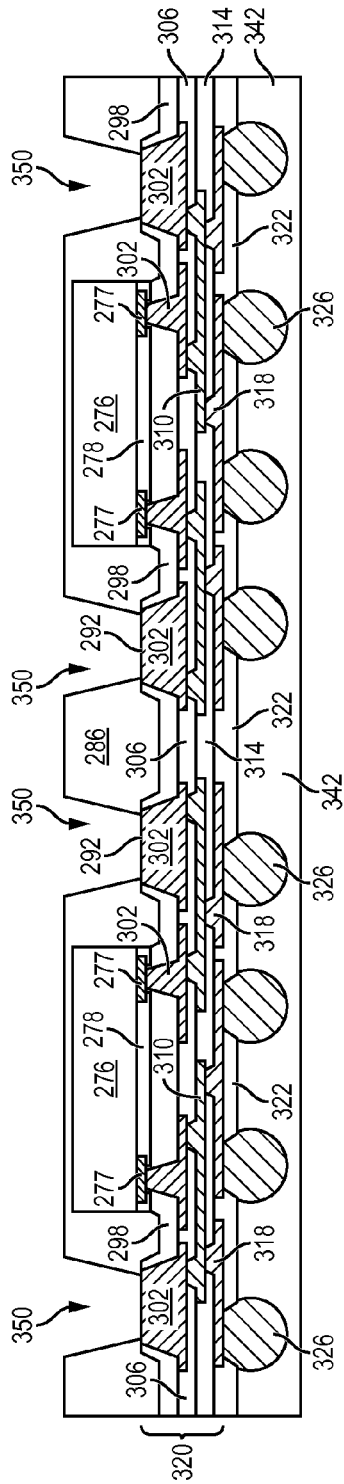


FIG. 13t

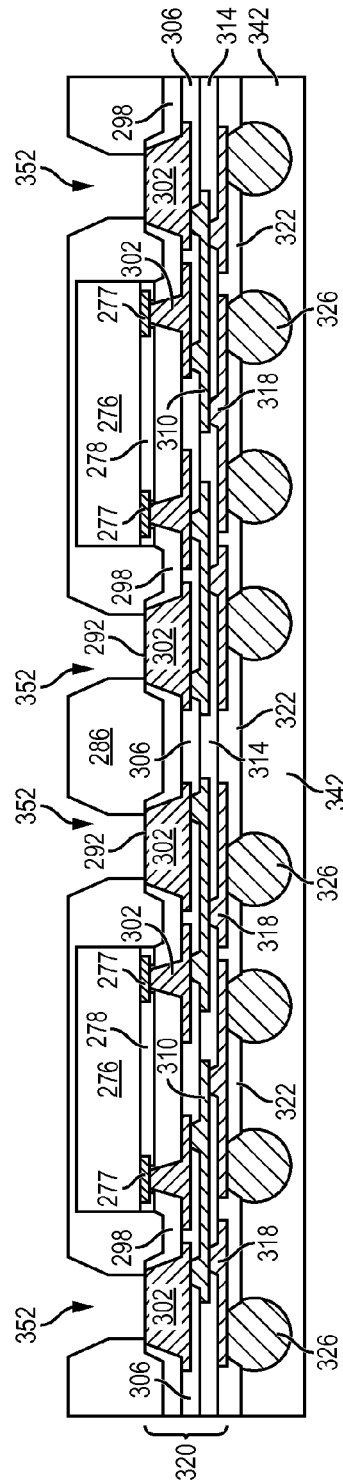


FIG. 13u

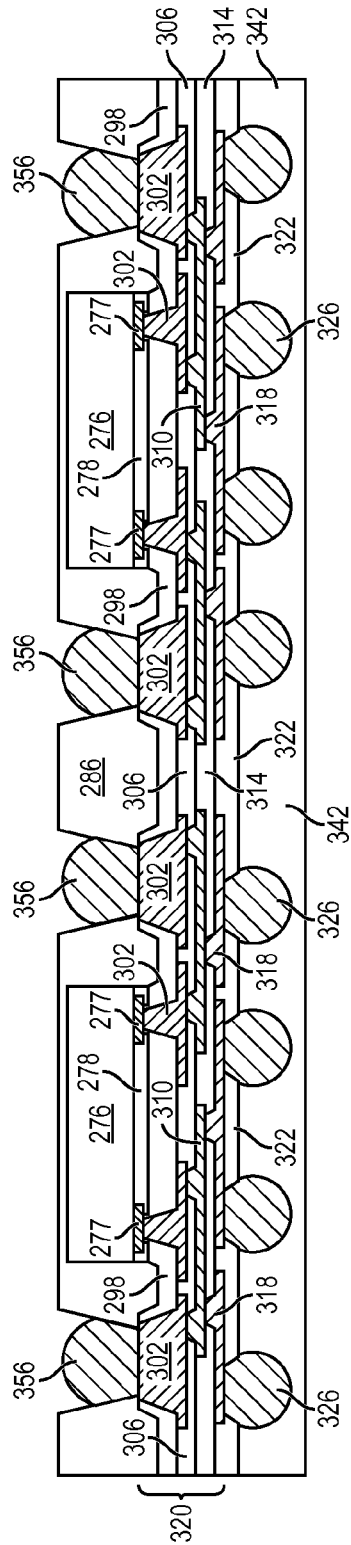


FIG. 13v

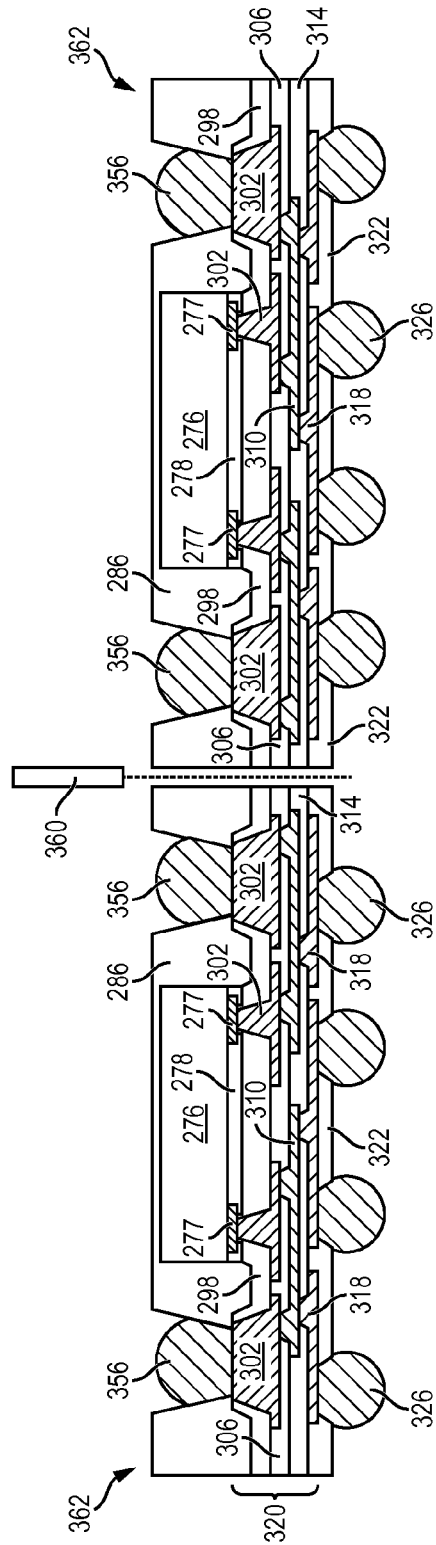


FIG. 13w

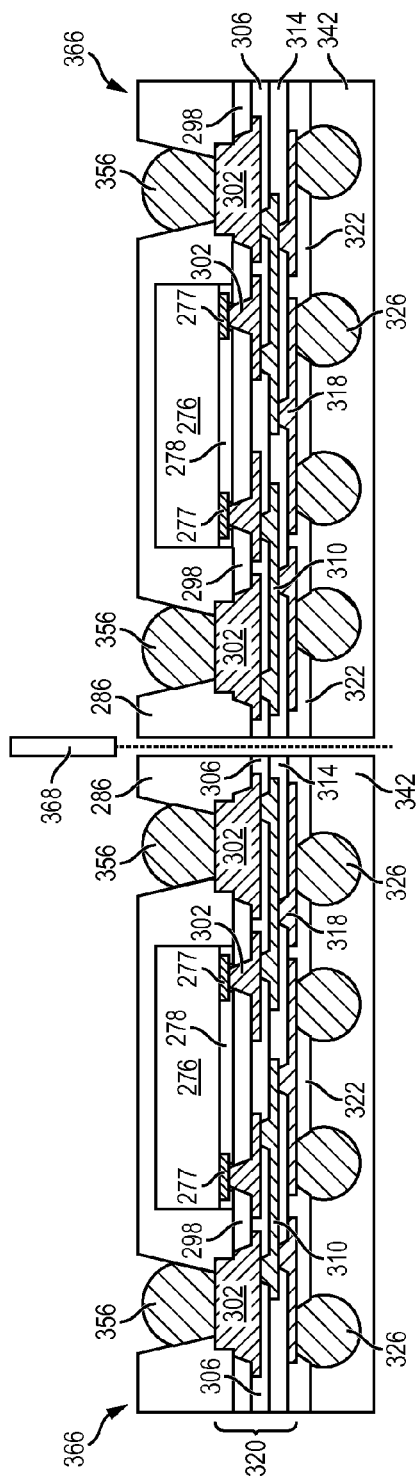


FIG. 13x

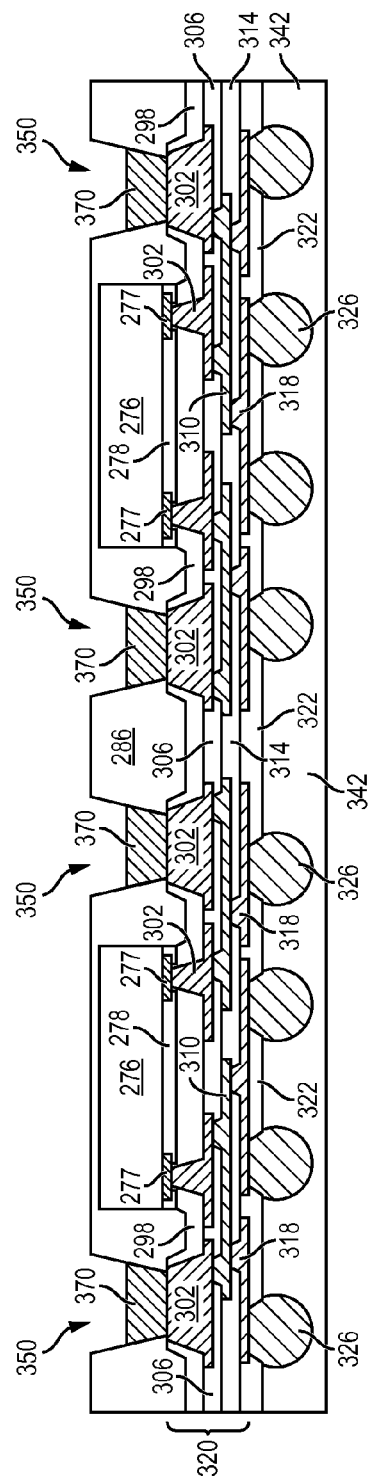


FIG. 14a

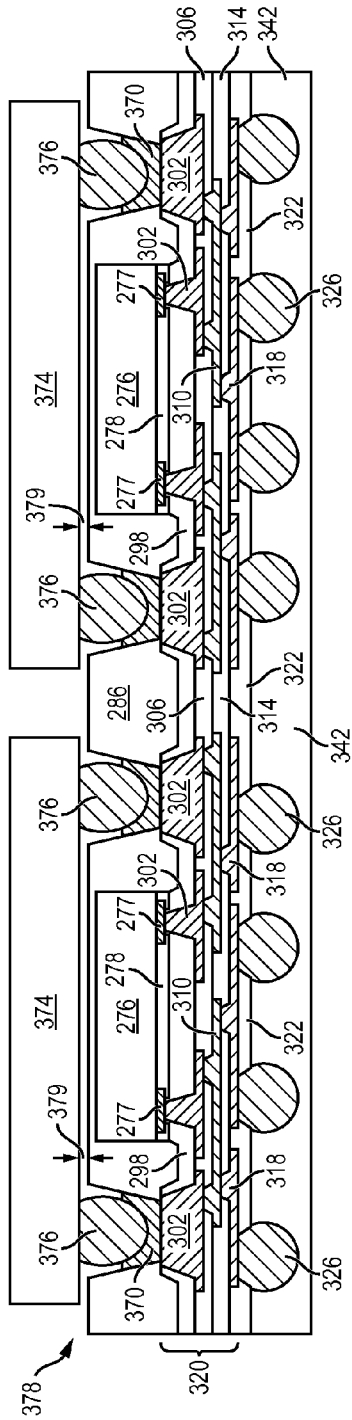


FIG. 14b

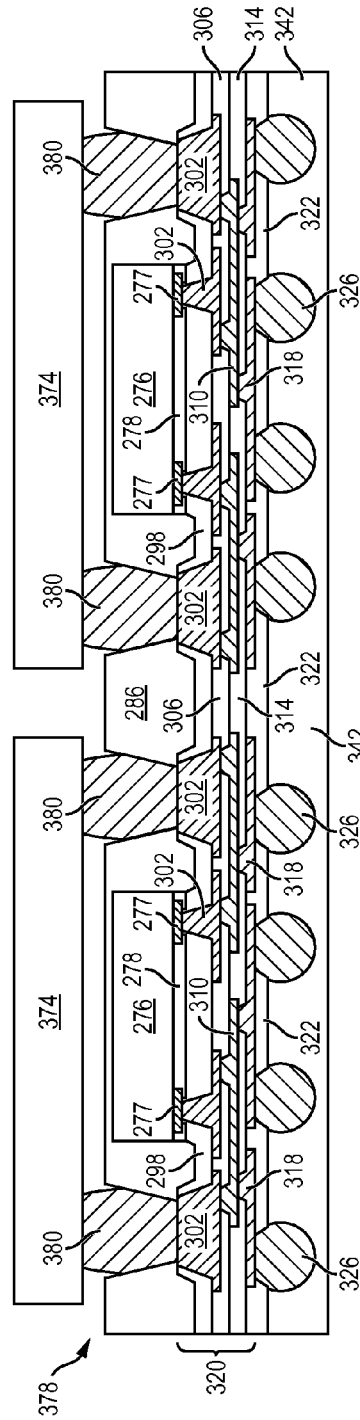


FIG. 14c

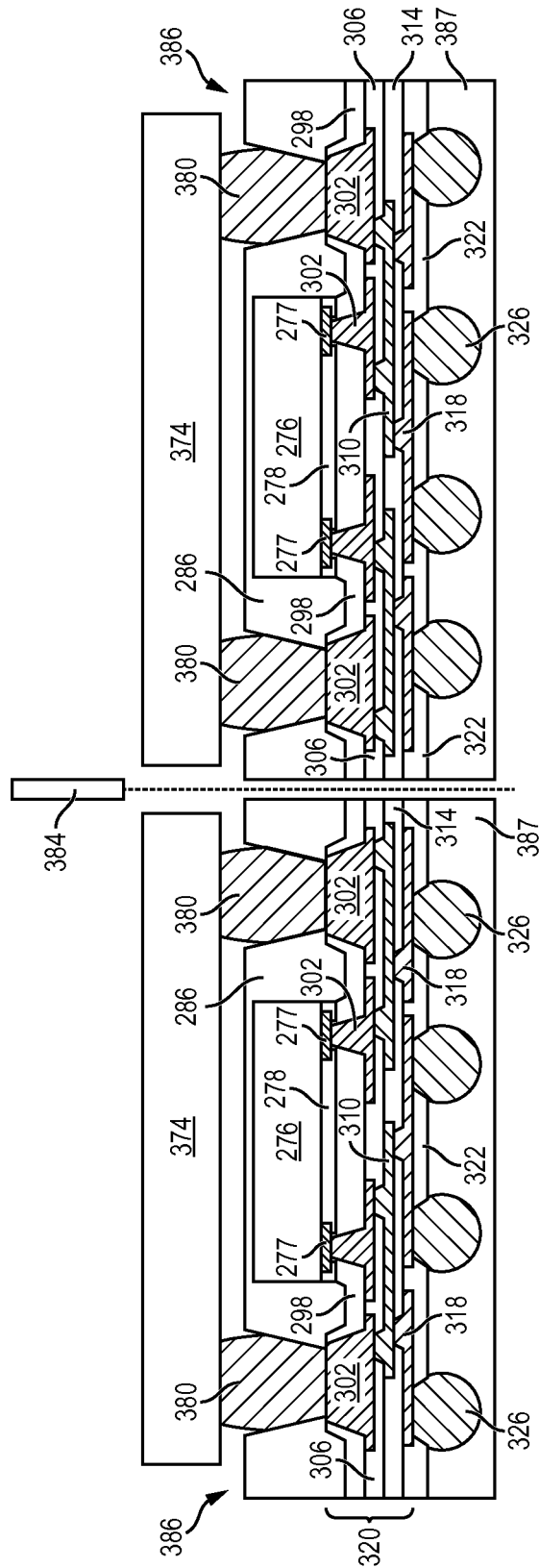


FIG. 14d

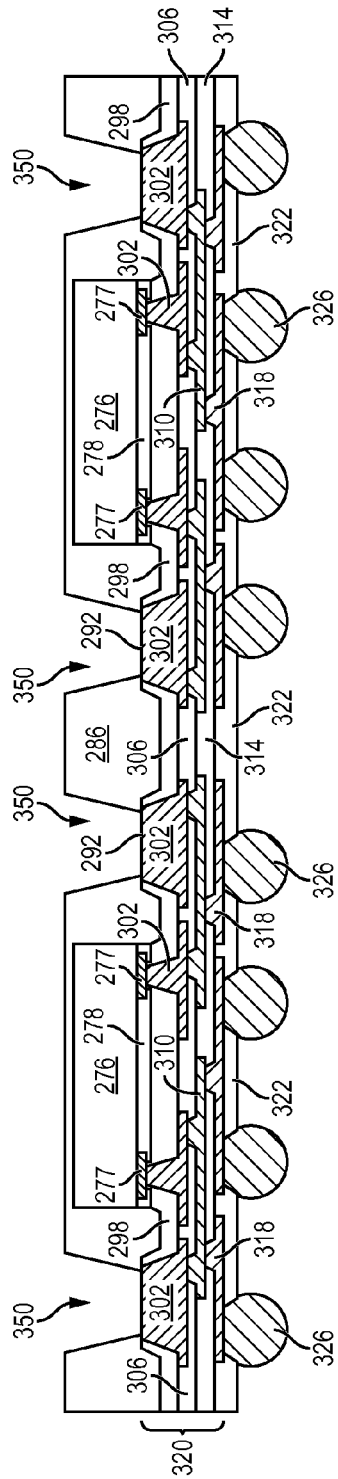


FIG. 15a

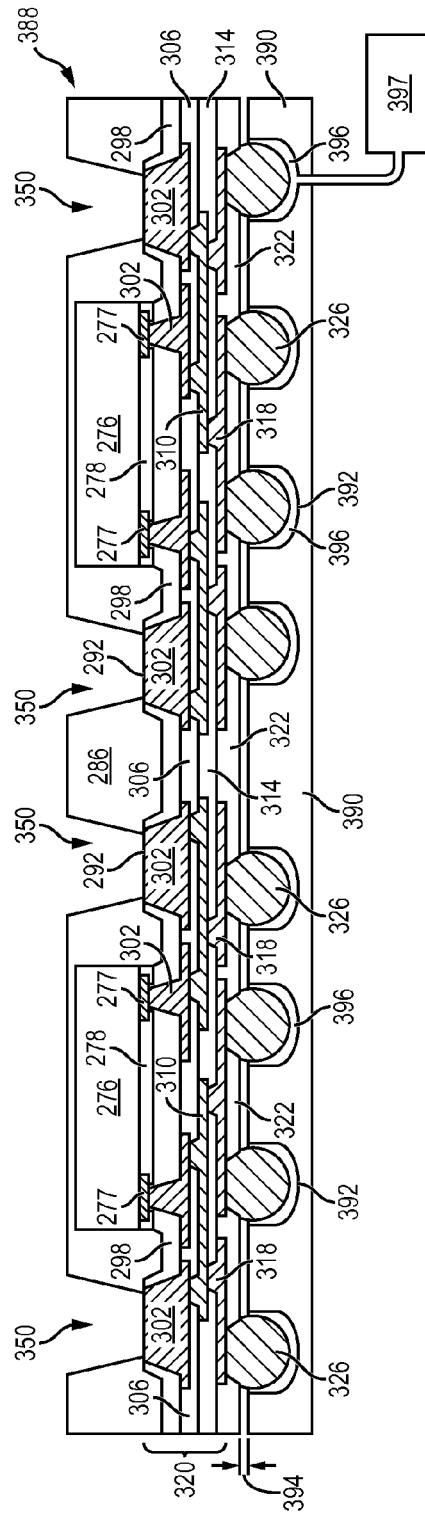


FIG. 15b

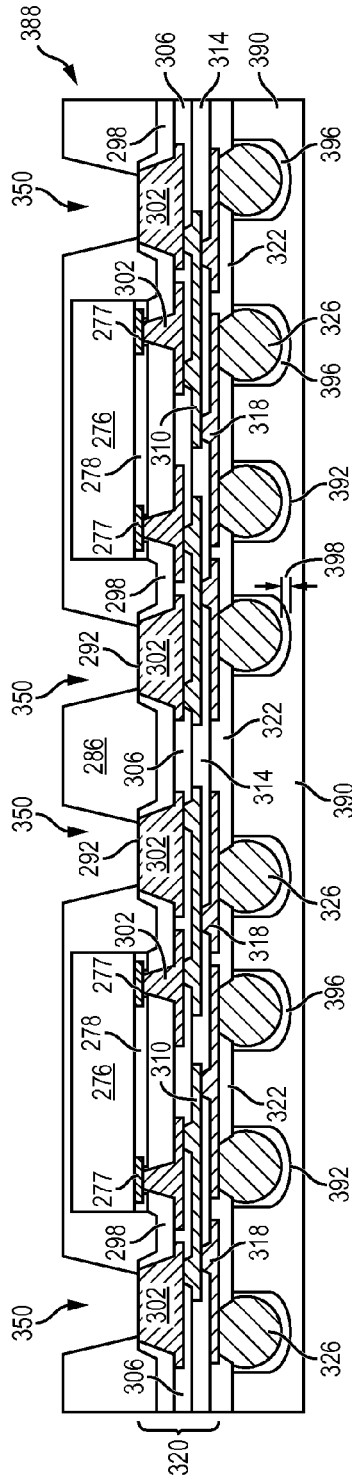


FIG. 15c

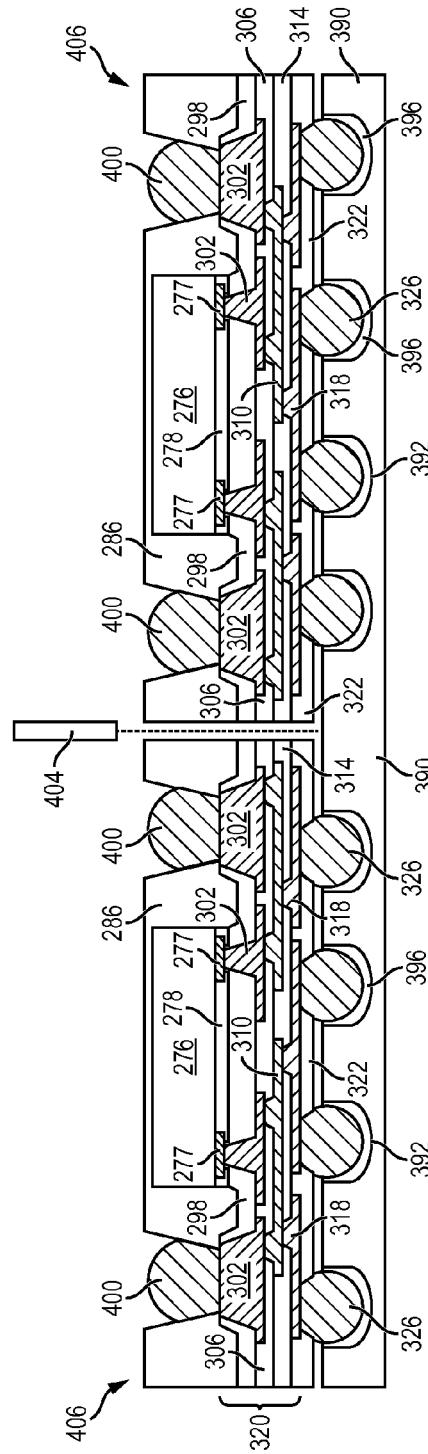


FIG. 15d

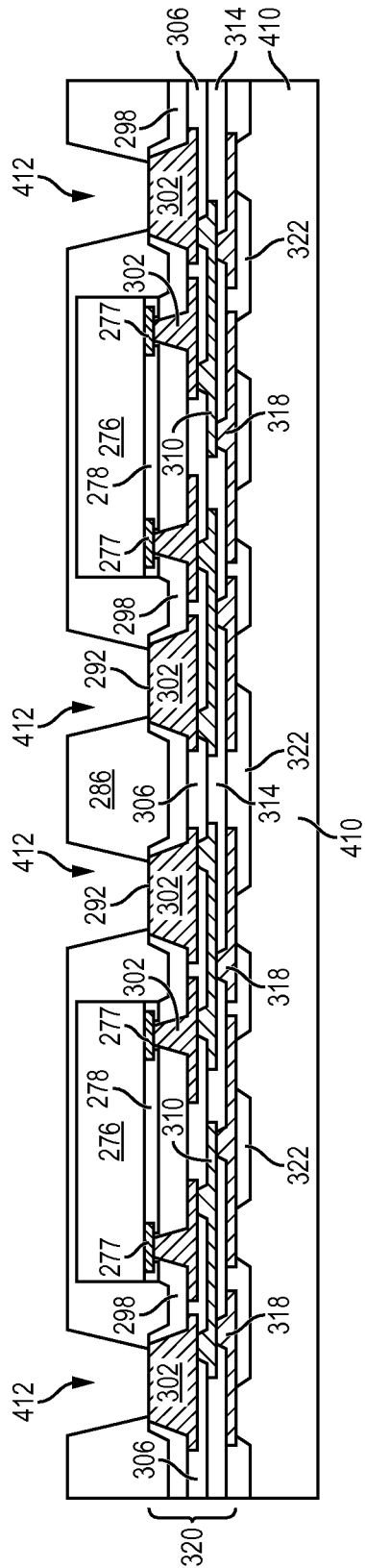


FIG. 16a

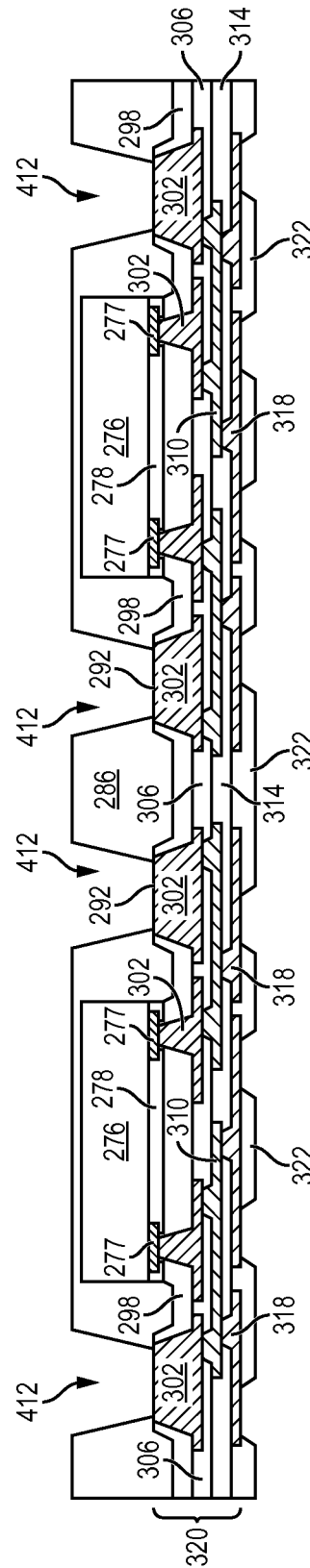


FIG. 16b

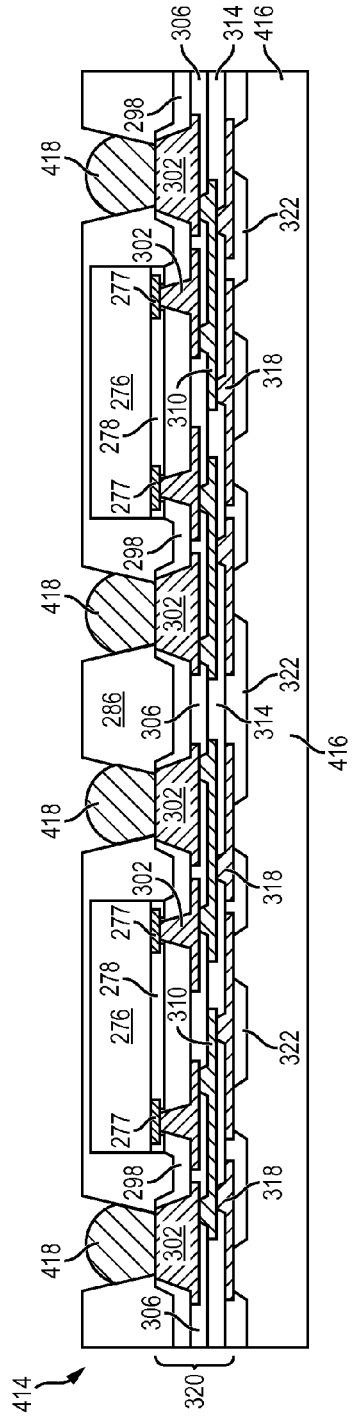


FIG. 16c

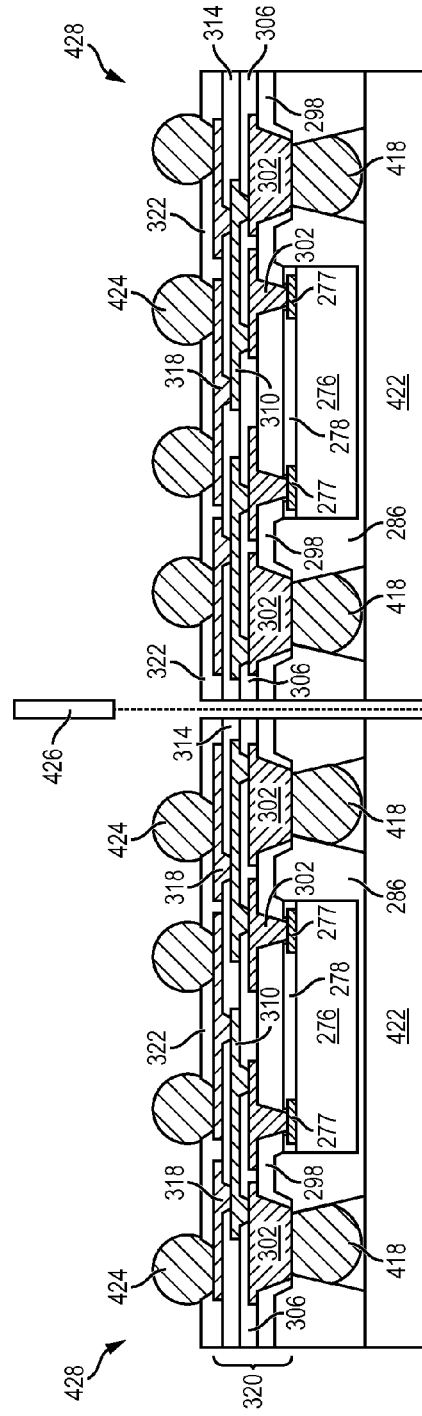


FIG. 16d

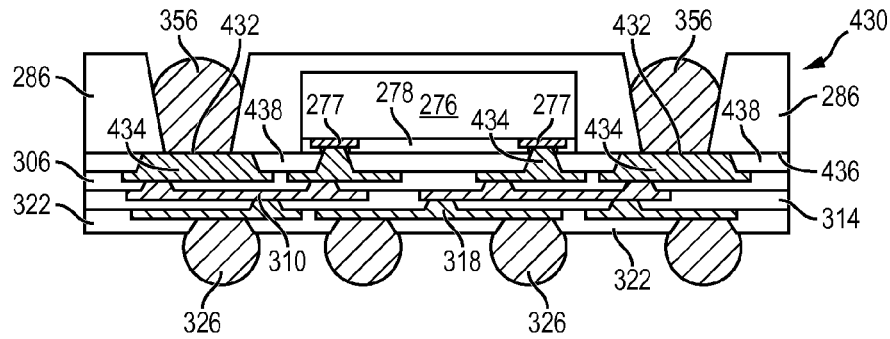


FIG. 17

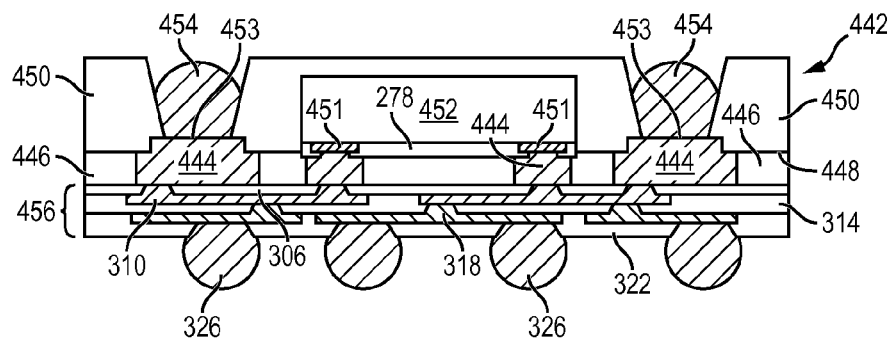


FIG. 18a

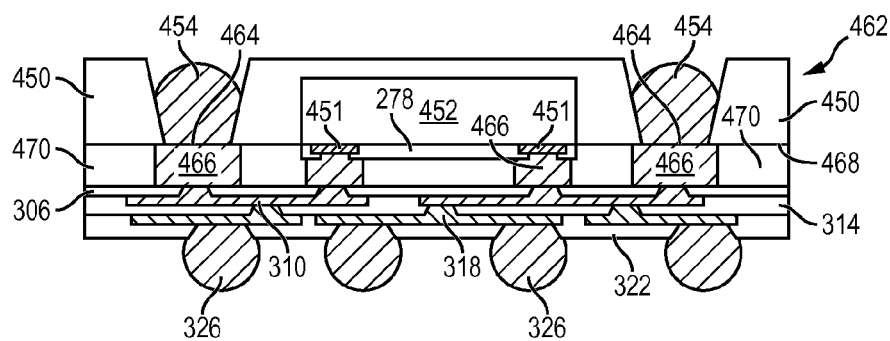


FIG. 18b

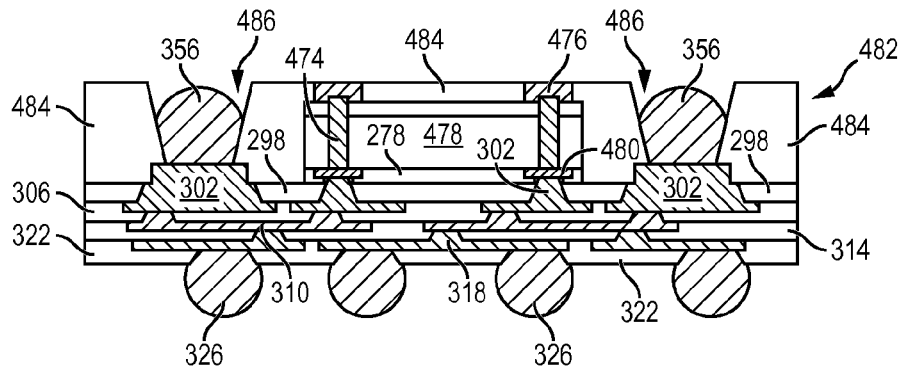


FIG. 19a

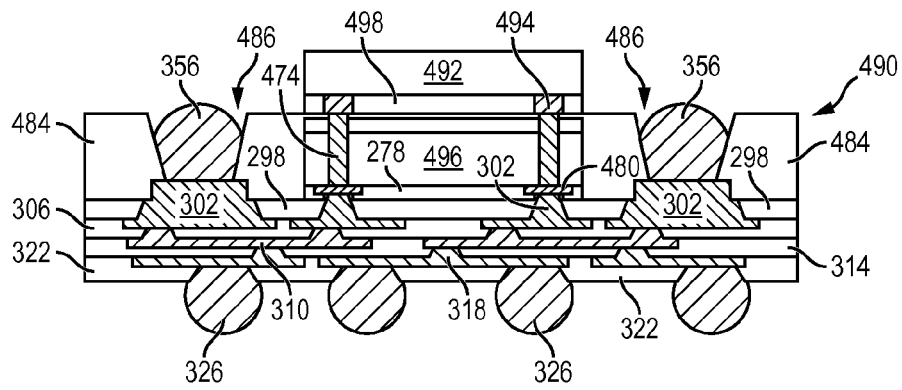


FIG. 19b

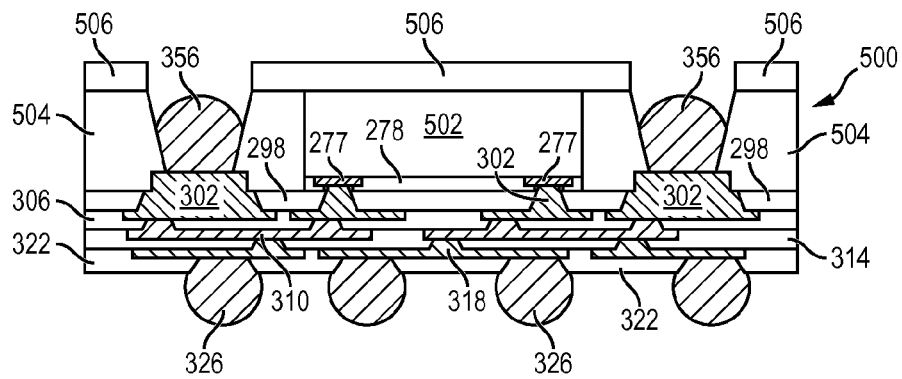


FIG. 20a

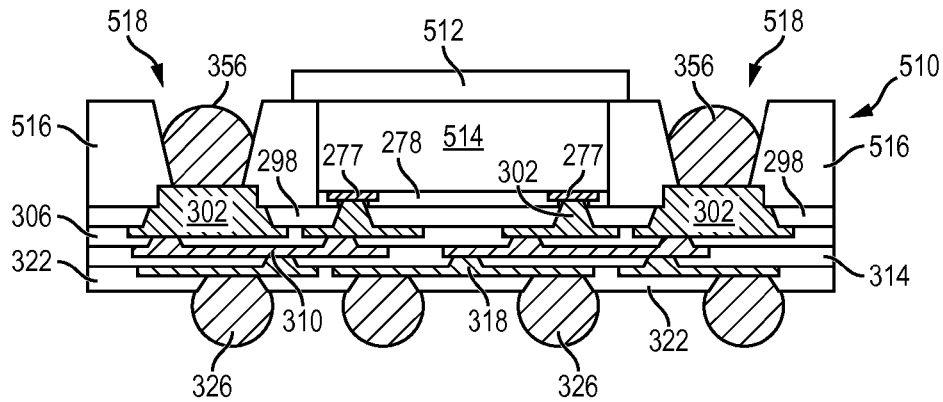


FIG. 20b

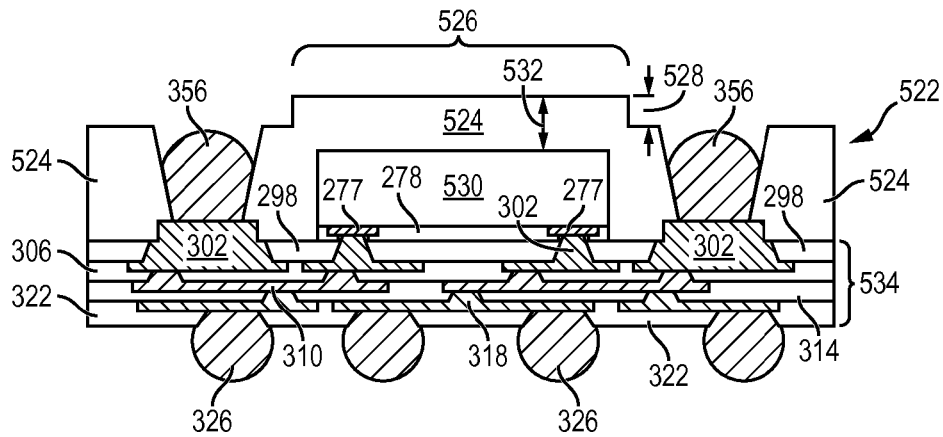


FIG. 21a

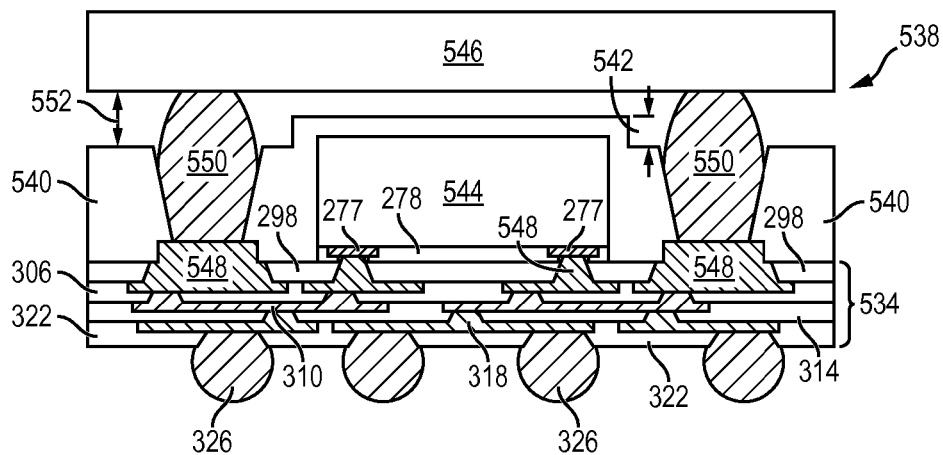


FIG. 21b

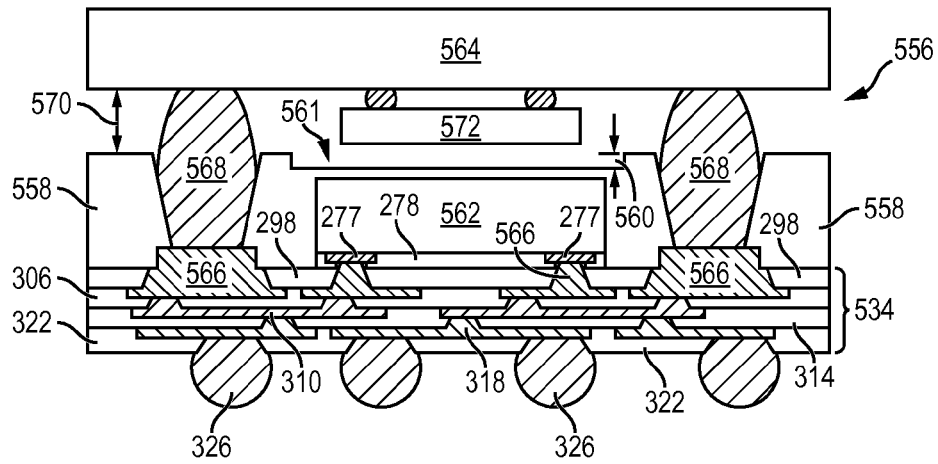


FIG. 21c

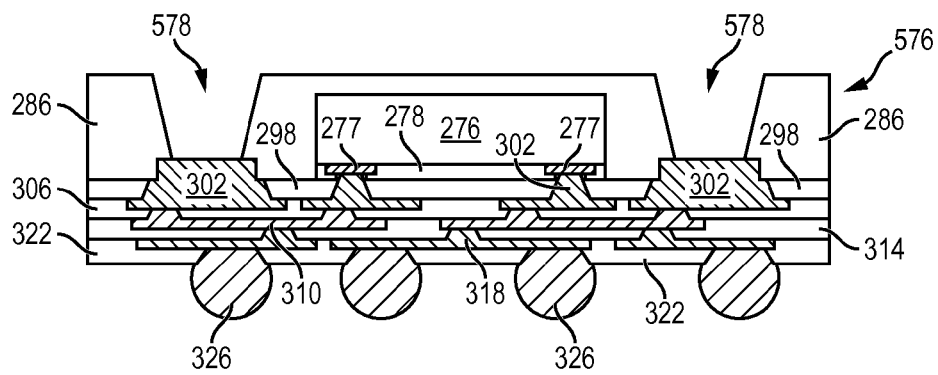


FIG. 22a

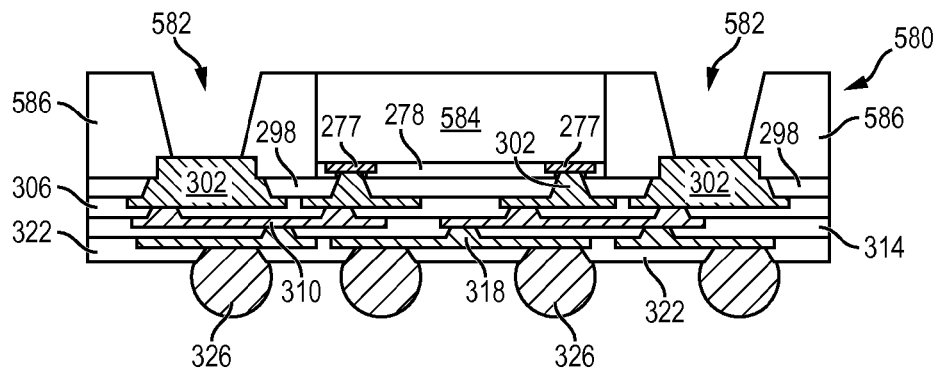


FIG. 22b

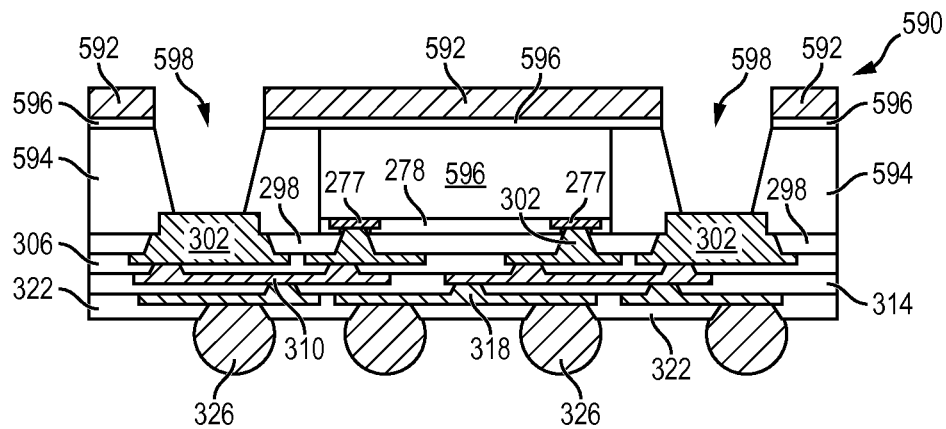


FIG. 22c

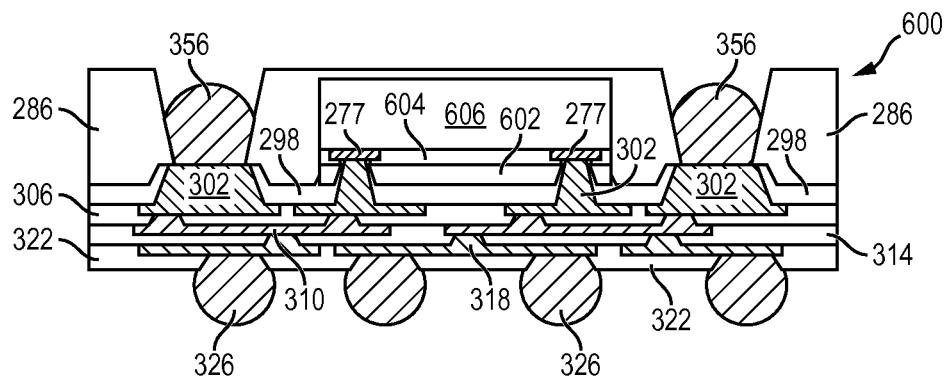


FIG. 23

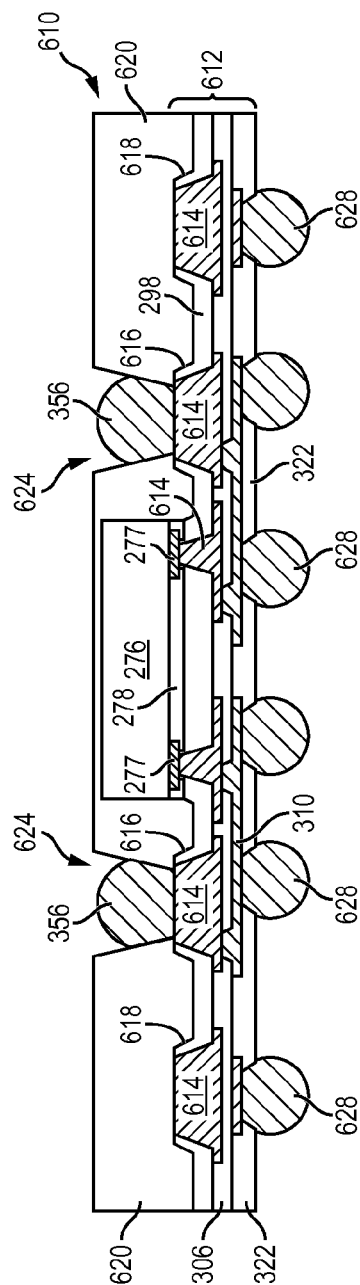


FIG. 24a

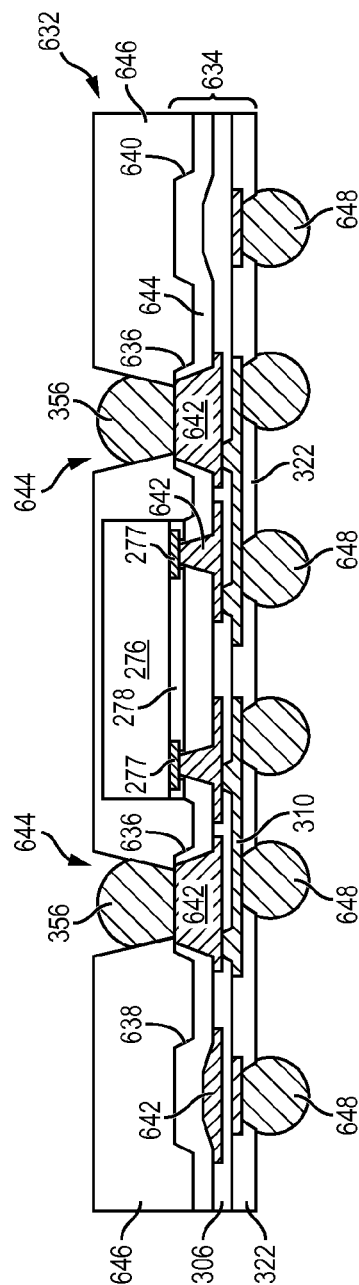


FIG. 24b

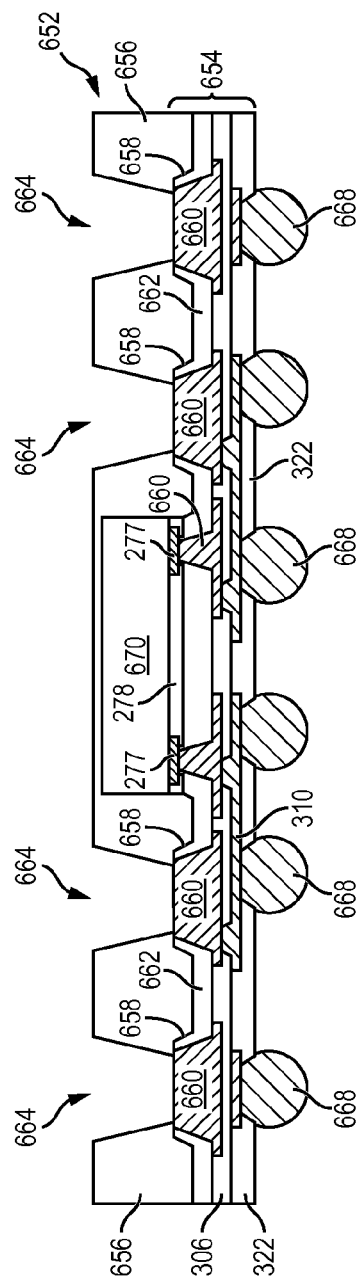


FIG. 25a

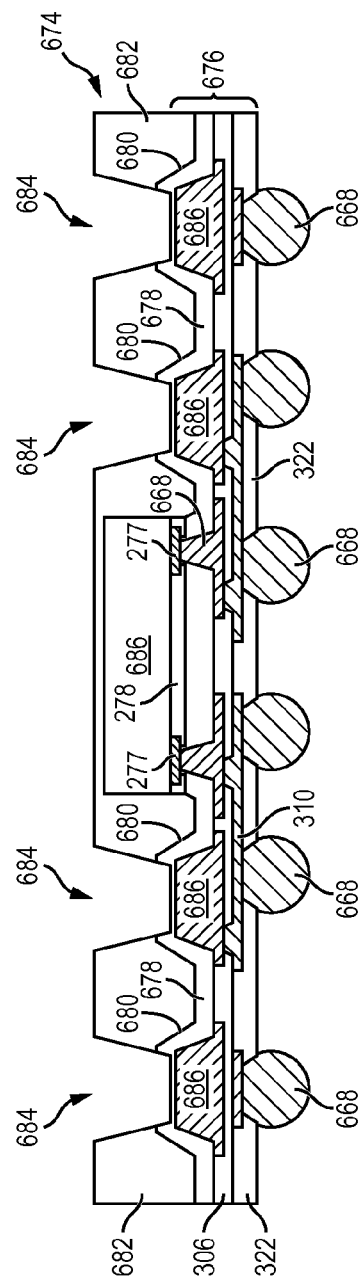


FIG. 25b

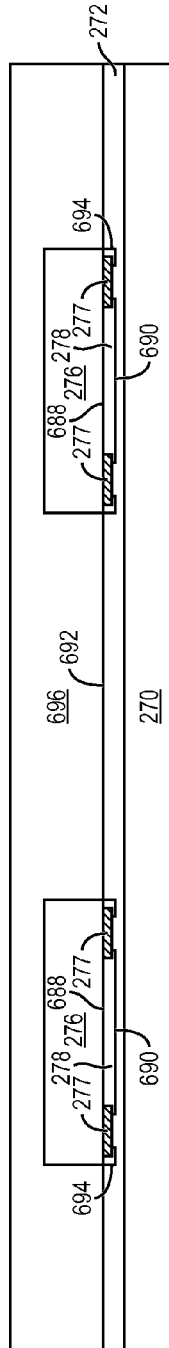


FIG. 26a

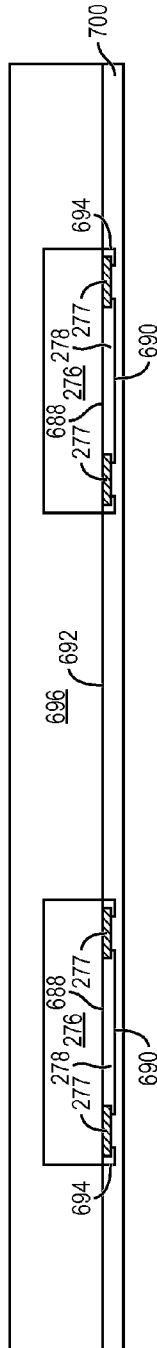


FIG. 26b

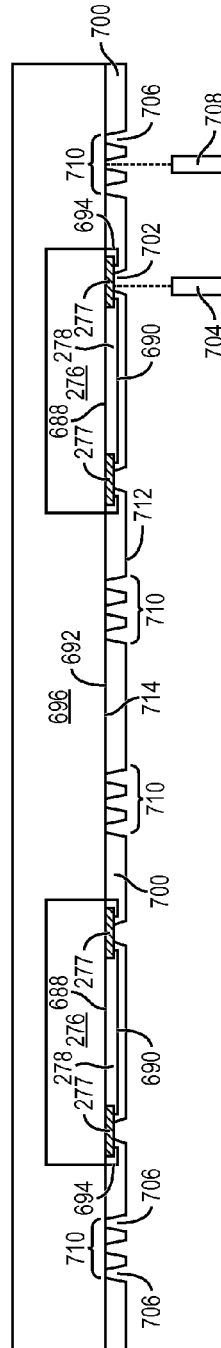
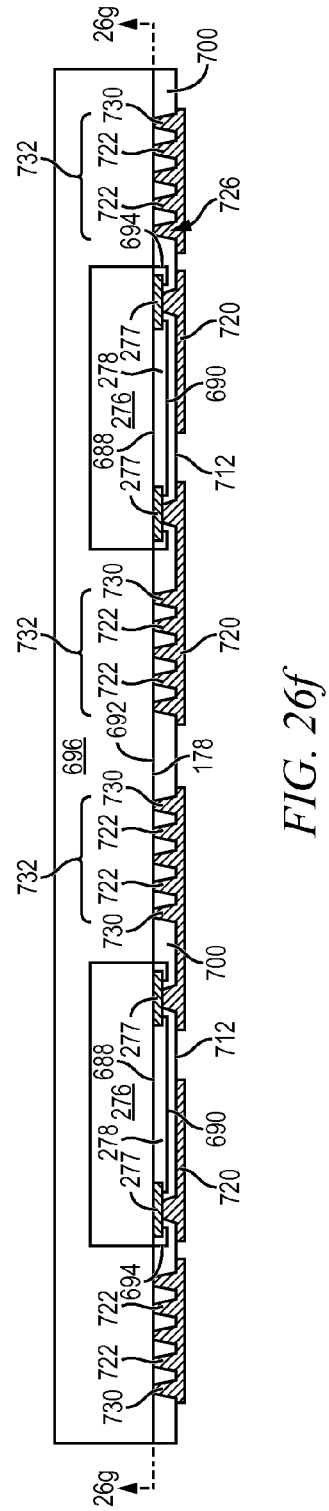
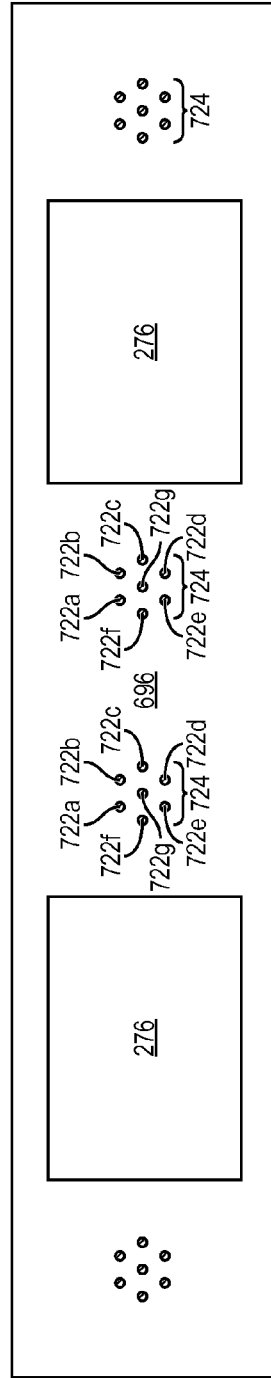
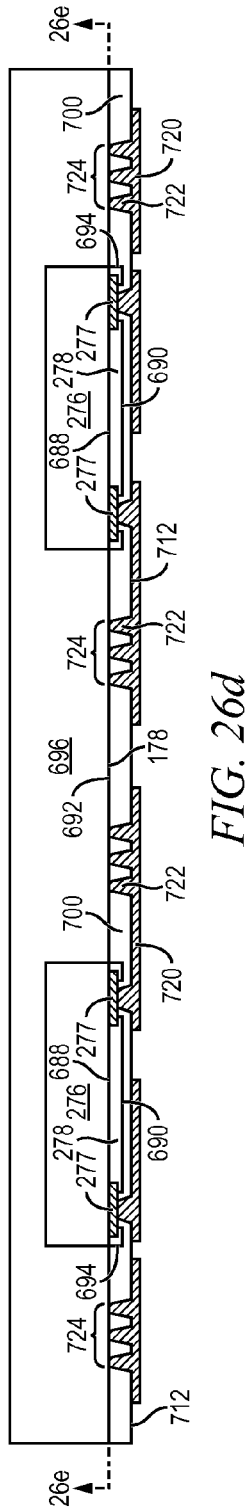


FIG. 26c



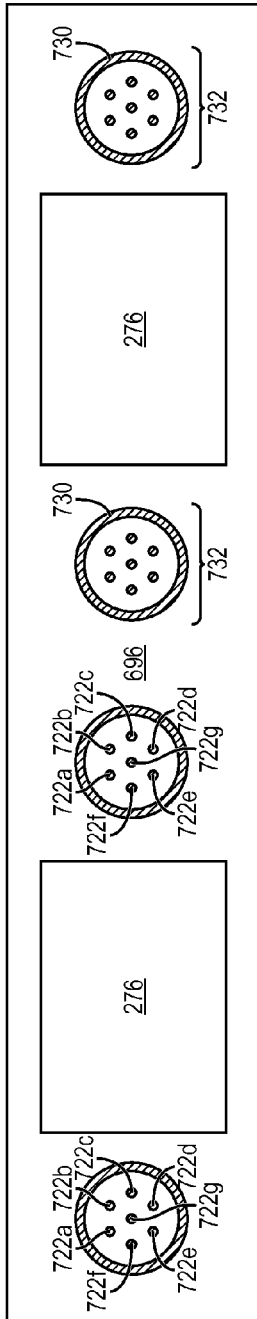


FIG. 26g

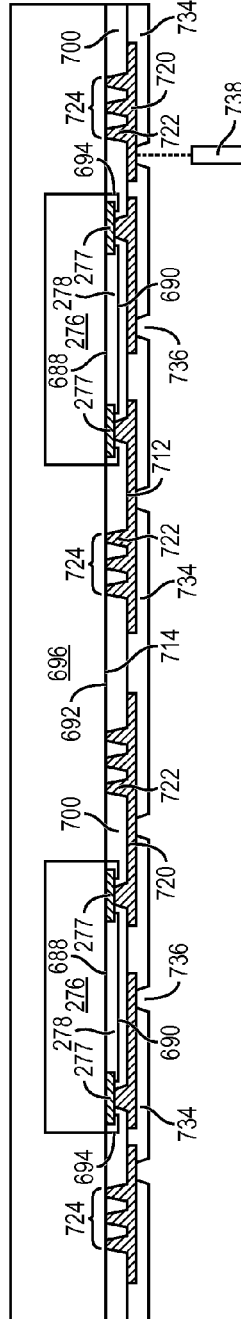


FIG. 26h

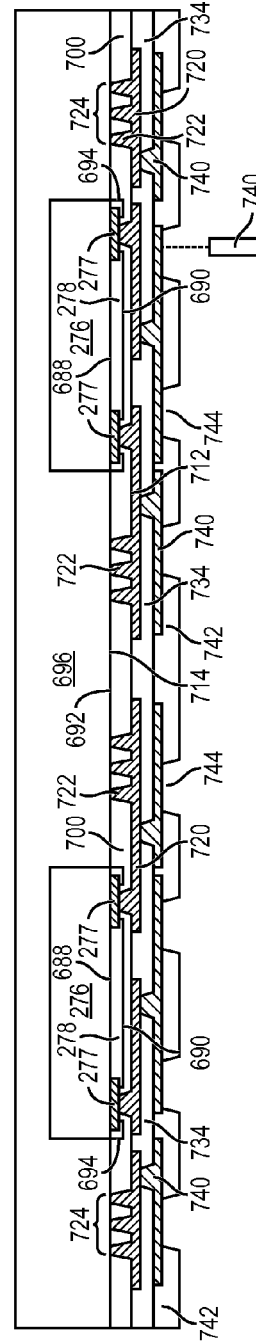


FIG. 26i

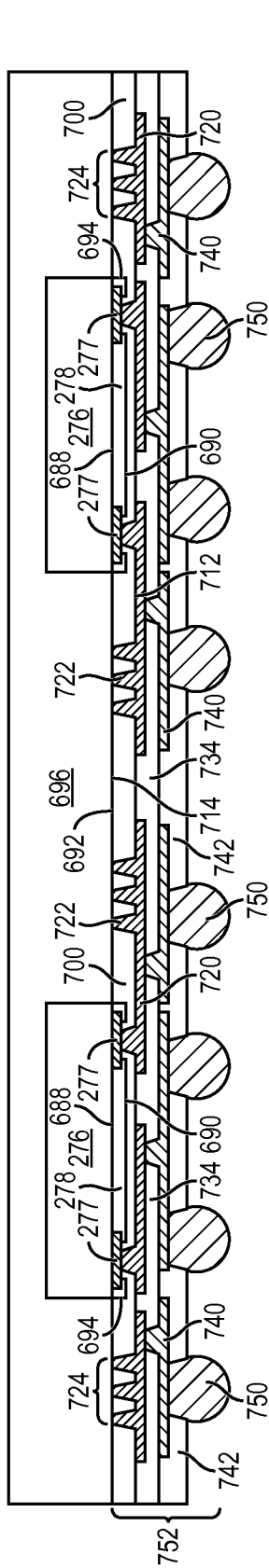


FIG. 26j

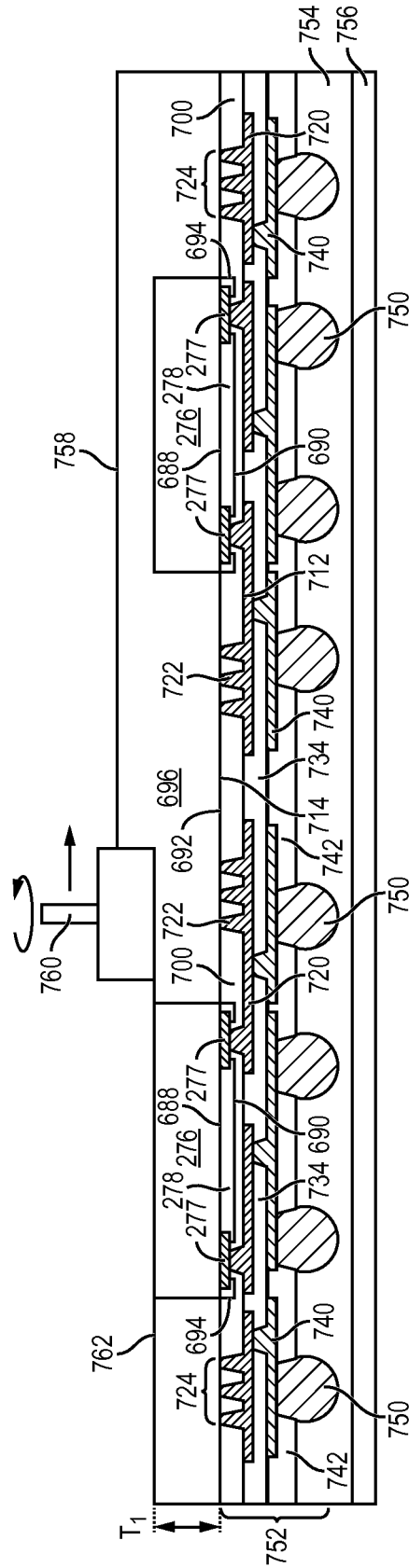


FIG. 26k

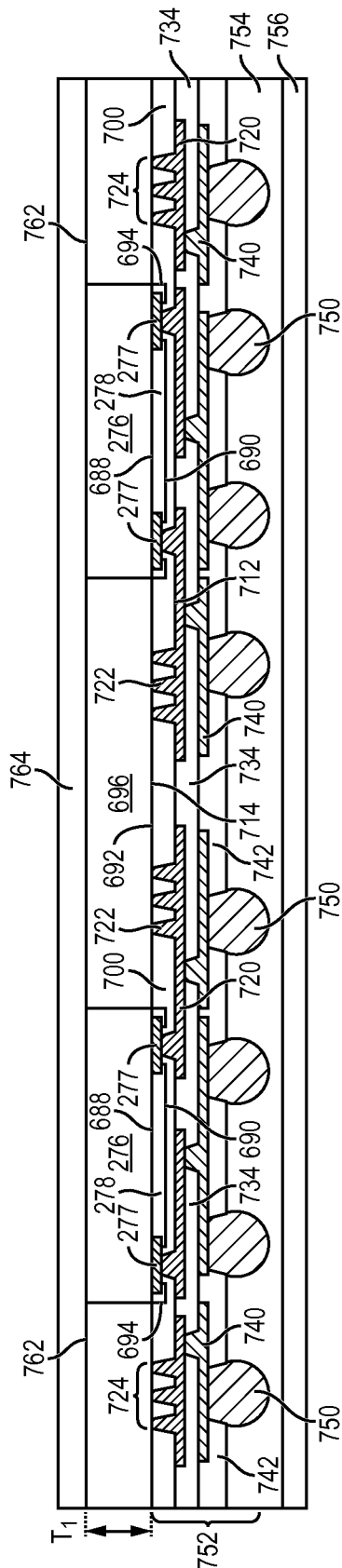


FIG. 261

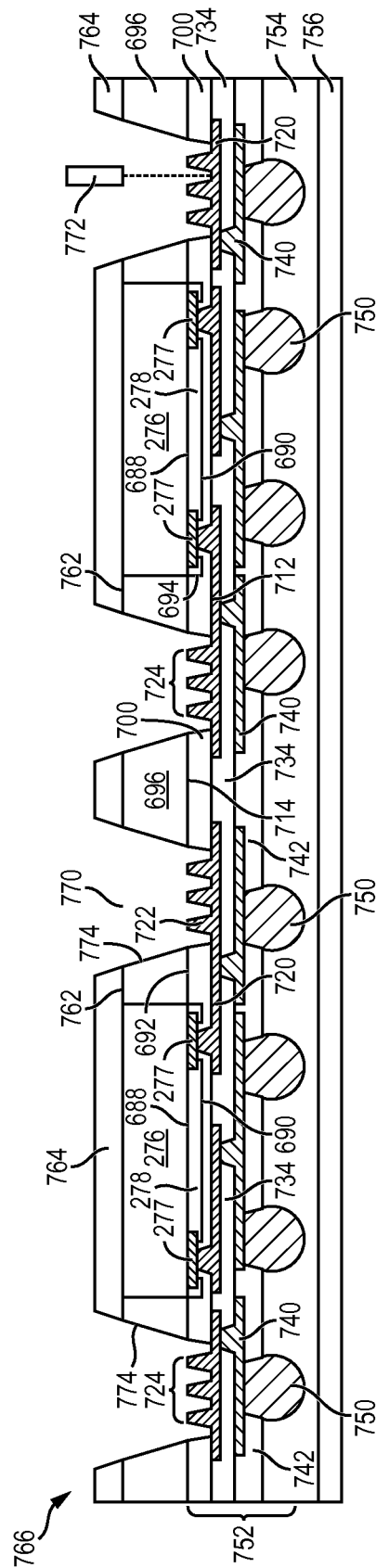


FIG. 26m

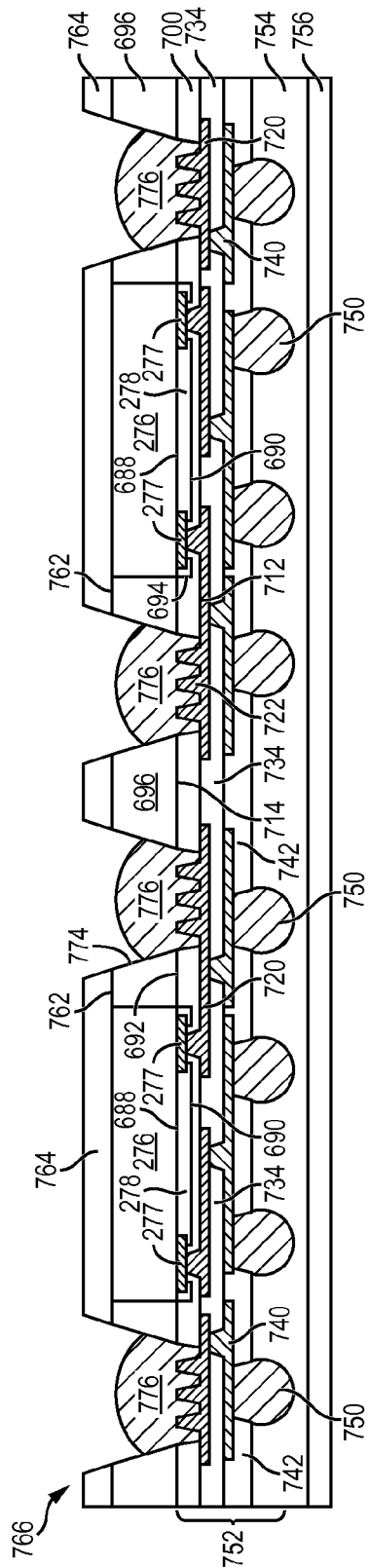


FIG. 26n

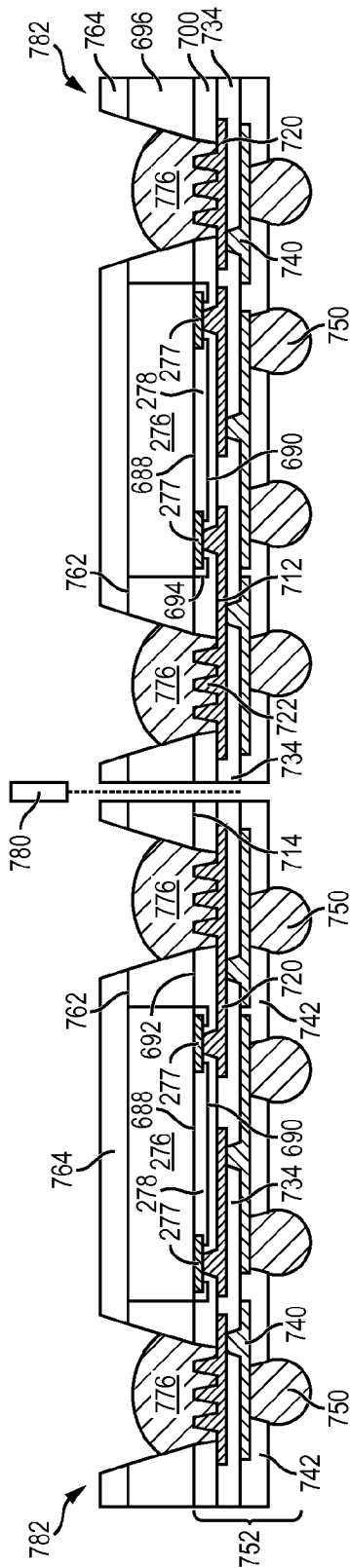


FIG. 260

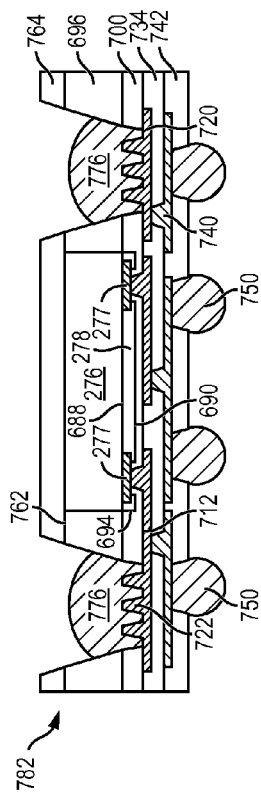


FIG. 26p

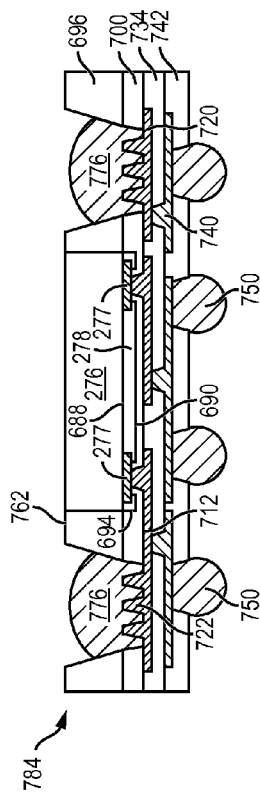


FIG. 26q

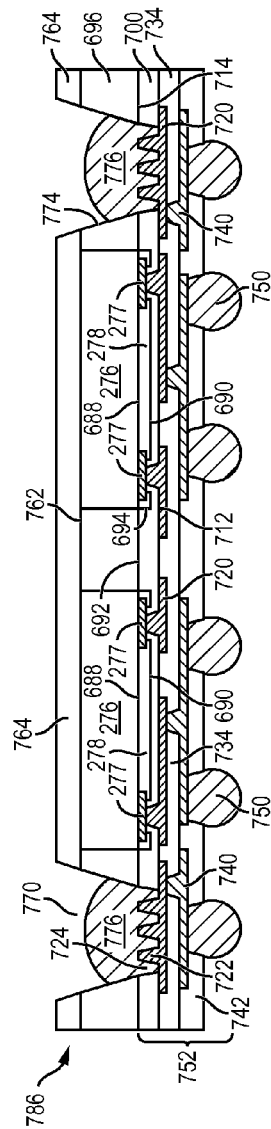


FIG. 27

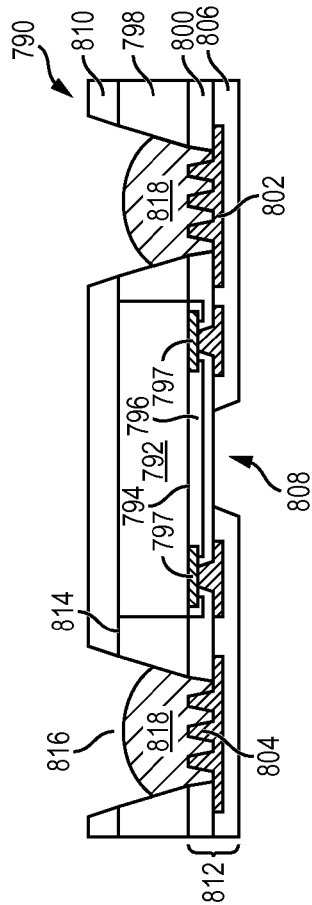


FIG. 28

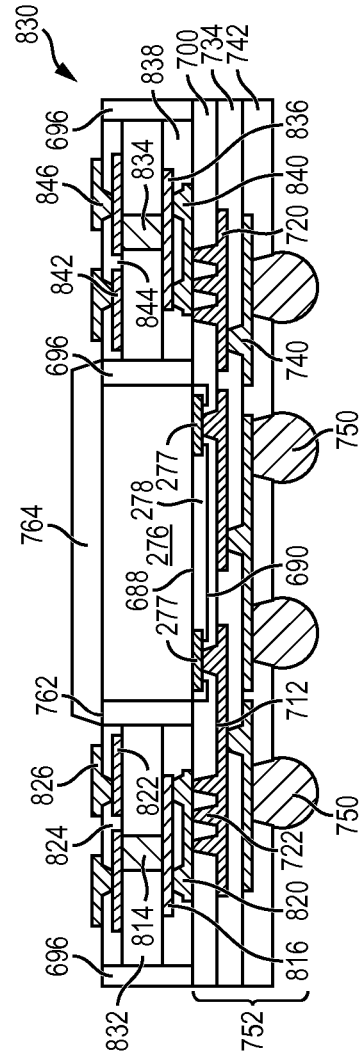


FIG. 29

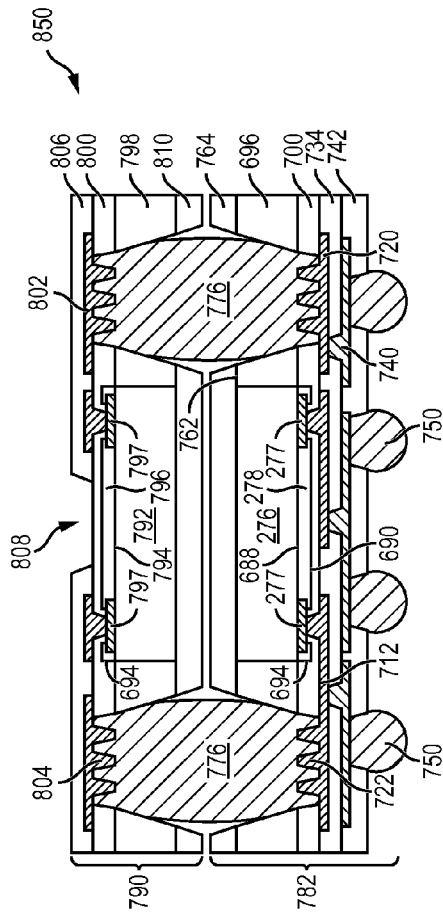


FIG. 30

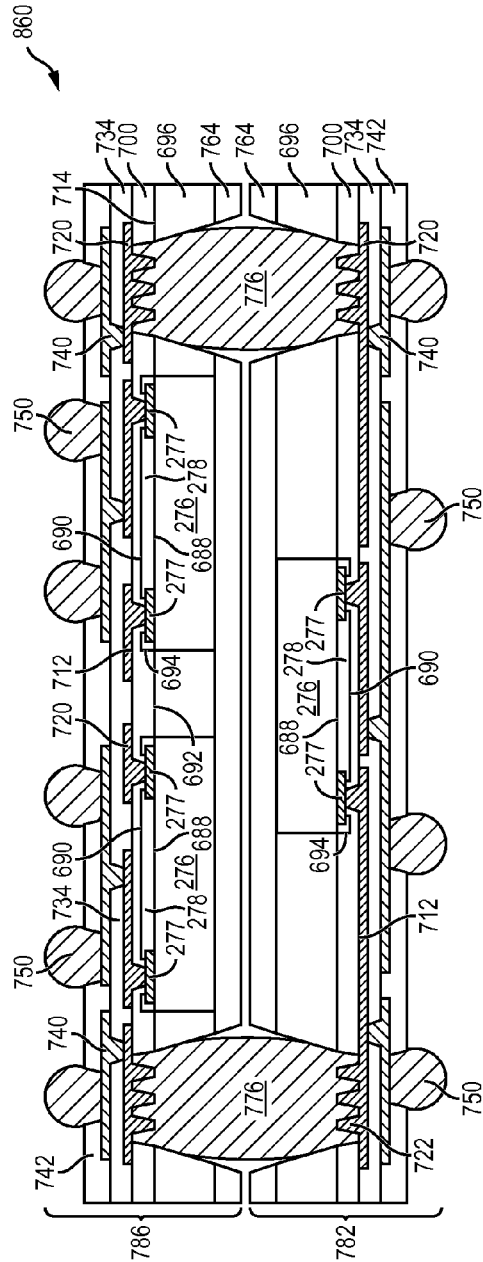


FIG. 31

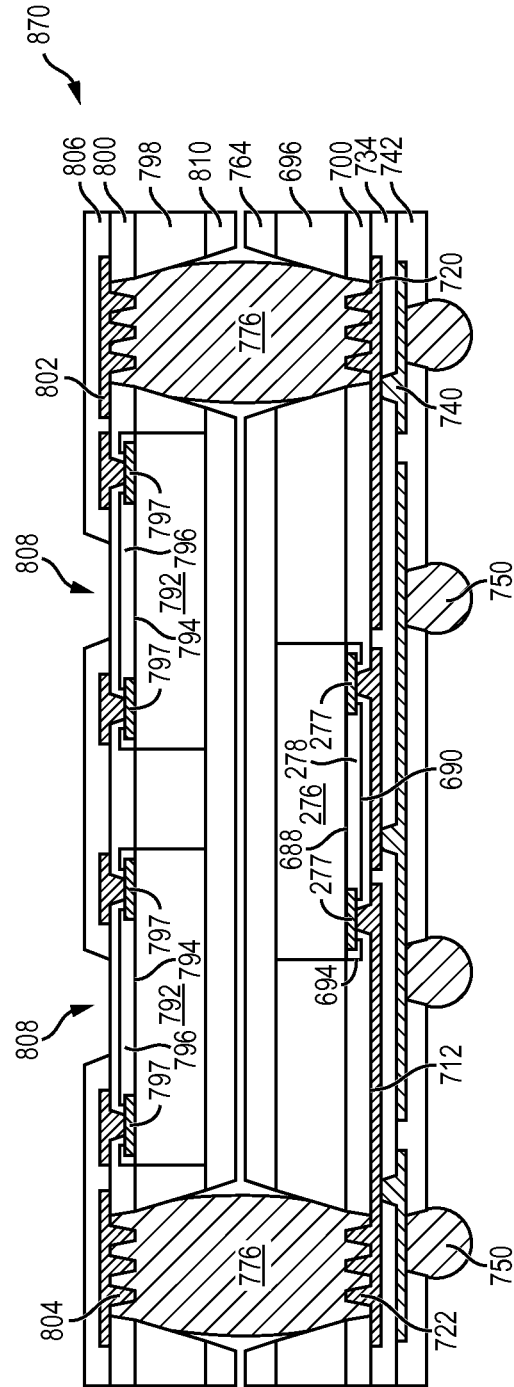


FIG. 32

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SEMICONDUCTOR DEVICE AND METHOD OF FORMING A VERTICAL INTERCONNECT STRUCTURE FOR 3-D FO-WLCSP

CLAIM TO DOMESTIC PRIORITY

The present application is a continuation-in-part of U.S. patent application Ser. No. 13/191,318, filed Jul. 26, 2011, which claims the benefit of U.S. Provisional Application No. 61/441,561, filed Feb. 10, 2011 and U.S. Provisional Application No. 61/444,914, filed Feb. 21, 2011, and further is a continuation-in-part of U.S. patent application Ser. No. 12/572,590, filed Oct. 2, 2009, which is a division of U.S. patent application Ser. No. 12/333,977, now U.S. Pat. No. 7,642,128, filed Dec. 12, 2008, and further is a continuation-in-part of U.S. application Ser. No. 13/326,128, filed Dec. 14, 2011, which applications are incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates in general to semiconductor devices and, more particularly, to a semiconductor device having a vertical interconnect structure for three-dimensional (3-D) fan-out wafer level chip scale packages (FO-WLCSPs).

BACKGROUND OF THE INVENTION

Semiconductor devices are commonly found in modern electronic products. Semiconductor devices vary in the number and density of electrical components. Discrete semiconductor devices generally contain one type of electrical component, e.g., light emitting diode (LED), small signal transistor, resistor, capacitor, inductor, and power metal oxide semiconductor field effect transistor (MOSFET). Integrated semiconductor devices typically contain hundreds to millions of electrical components. Examples of integrated semiconductor devices include microcontrollers, microprocessors, charged-coupled devices (CCDs), solar cells, and digital micro-mirror devices (DMDs).

Semiconductor devices perform a wide range of functions such as signal processing, high-speed calculations, transmitting and receiving electromagnetic signals, controlling electronic devices, transforming sunlight to electricity, and creating visual projections for television displays. Semiconductor devices are found in the fields of entertainment, communications, power conversion, networks, computers, and consumer products. Semiconductor devices are also found in military applications, aviation, automotive, industrial controllers, and office equipment.

Semiconductor devices exploit the electrical properties of semiconductor materials. The atomic structure of semiconductor material allows its electrical conductivity to be manipulated by the application of an electric field or base current or through the process of doping. Doping introduces impurities into the semiconductor material to manipulate and control the conductivity of the semiconductor device.

A semiconductor device contains active and passive electrical structures. Active structures, including bipolar and field effect transistors, control the flow of electrical current. By varying levels of doping and application of an electric field or base current, the transistor either promotes or restricts the flow of electrical current. Passive structures, including resistors, capacitors, and inductors, create a relationship between voltage and current necessary to perform a variety of electrical functions. The passive and active structures are electri-

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cally connected to form circuits, which enable the semiconductor device to perform high-speed calculations and other useful functions.

A semiconductor die has an active surface containing analog or digital circuits implemented as active devices, passive devices, conductive layers, and dielectric layers formed within the die and electrically interconnected according to the electrical design and function of the die. The active surface performs the electrical and mechanical design function of the semiconductor die. The active surface may also contain a sensor such as a photodiode, phototransistor, Hall effect device, piezoelectric device, nanoelectronic device, and microelectromechanical device. The active surface responds to stimulus such as light, sound, heat, electromagnetic radiation, electric fields, magnetic fields, motion, ionizing radiation, vibration, motion, acceleration, rotation, pressure, and temperature to enable the semiconductor die to perform design functions. For example, an optical sensor on the active surface reacts to light which passes through an opening or window in the semiconductor package to reach the sensor.

Semiconductor devices are generally manufactured using two complex manufacturing processes, i.e., front-end manufacturing, and back-end manufacturing, each involving potentially hundreds of steps. Front-end manufacturing involves the formation of a plurality of die on the surface of a semiconductor wafer. Each semiconductor die is typically identical and contains circuits formed by electrically connecting active and passive components. Back-end manufacturing involves singulating individual semiconductor die from the finished wafer and packaging the die to provide structural support and environmental isolation. The term "semiconductor die" as used herein refers to both the singular and plural form of the words, and accordingly can refer to both a single semiconductor device and multiple semiconductor devices.

One goal of semiconductor manufacturing is to produce smaller semiconductor devices. Smaller devices typically consume less power, have higher performance, and can be produced more efficiently. In addition, smaller semiconductor devices have a smaller footprint, which is desirable for smaller end products. A smaller semiconductor die size can be achieved by improvements in the front-end process resulting in semiconductor die with smaller, higher density active and passive components. Back-end processes may result in semiconductor device packages with a smaller footprint by improvements in electrical interconnection and packaging materials.

Another goal of semiconductor manufacturing is to produce semiconductor devices with adequate heat dissipation. High frequency semiconductor devices generally generate more heat. Without effective heat dissipation, the generated heat can reduce performance, decrease reliability, and reduce the useful lifetime of the semiconductor device.

In a conventional FO-WLCSP, a semiconductor die with contact pads is mounted to a carrier. An encapsulant is deposited over the semiconductor die and the carrier. The carrier is removed and a build-up interconnect structure is formed over the encapsulant and semiconductor die. The electrical interconnection between a FO-WLCSP containing semiconductor devices on multiple levels (3-D device integration) and external devices can be accomplished by forming redistribution layers (RDLs) within a build-up interconnect structure over both a front side and a backside of a semiconductor die within a FO-WLCSP. The formation of multiple RDLs including over a front side and backside of a semiconductor die can be a slow and costly approach for making electrical interconnection for 3-D FO-WLCSPs and can result in higher fabrication costs. Furthermore, the RDLs of build-up interconnect struc-

tures are prone to cracking and warping under stress, which can propagate through the RDLs to the semiconductor die and contact pads causing defects in the electrical interconnection. Conductive interconnect structures can be formed within the FO-WLCSPs and electrically connected to the RDLs to provide vertical electrical interconnection for 3-D device integration. Conductive interconnect structures formed within FO-WLCSPs can have poor electrical and mechanical connectivity with the RDLs. Additionally, the process of forming conductive interconnect structures can reduce structural support for the RDLs, particularly when openings are formed in the package over the RDLs. Forming build-up interconnect structures and conductive interconnect structures within FO-WLCSPs can also lead to warpage before and after removal of the carrier.

3-D device integration can be accomplished with conductive through silicon vias (TSV) or through hole vias (THV). In most TSVs and THVs, the sidewalls and bottom-side of the via are conformally plated with conductive materials to enhance adhesion. The TSVs and THVs are then filled with another conductive material, for example, by copper deposition through an electroplating process. The TSV and THV formation typically involves considerable time for the via filling, which reduces the unit-per-hour (UPH) production schedule. The equipment need for electroplating, e.g., plating bath, and sidewall passivation increases manufacturing cost. In addition, voids may be formed within the vias, which causes defects and reduces reliability of the device. TSV and THV can be a slow and costly approach to make vertical electrical interconnections in semiconductor packages. These interconnect schemes also have problems with semiconductor die placement accuracy, warpage control before and after removal of the carrier, and process cost management.

The electrical interconnection between 3-D FO-WLCSPs and external devices, in addition to including TSVs and THVs, further includes RDLs. RDLs serve as intermediate layers for electrical interconnect within a package including electrical interconnect with package I/O pads which provide electrical connection from semiconductor die within 3-D FO-WLCSP to points external to 3-D FO-WLCSPs. RDLs can be formed over both a front side and a backside of a semiconductor die within a 3-D FO-WLCSP. However, the formation of multiple RDLs including over a front side and backside of a semiconductor die can be a slow and costly approach for making electrical interconnection for 3-D FO-WLCSPs and can result in higher fabrication costs.

SUMMARY OF THE INVENTION

A need exists for a simple, cost effective, and reliable vertical electrical interconnect structure for 3-D semiconductor devices including an active region that is responsive to an external stimulus. Accordingly, in one embodiment, the present invention is a method of making a semiconductor device comprising the steps of providing a semiconductor die, depositing an encapsulant over a first surface of the semiconductor die and around the semiconductor die, forming a first insulating layer over a second surface of the semiconductor die opposite the first surface, forming a first conductive layer over the first insulating layer, forming an opening in the encapsulant to expose the first conductive layer, and depositing a conductive material within the opening.

In another embodiment, the present invention is a method of making a semiconductor device comprising the steps of providing a semiconductor die, depositing an encapsulant over a first surface of the semiconductor die and around the

semiconductor die, forming a first insulating layer over a second surface of the semiconductor die opposite the first surface, forming a conductive layer over the first insulating layer, and forming an interconnect structure through the encapsulant electrically connected to the conductive layer.

In another embodiment, the present invention is a method of making a semiconductor device comprising the steps of providing a semiconductor die, forming a first insulating layer over the semiconductor die, forming a conductive layer over the first insulating layer, and forming an interconnect structure outside a footprint of the semiconductor die electrically connected to the conductive layer.

In another embodiment, the present invention is a semiconductor device including a semiconductor die and an encapsulant deposited over a first surface of the semiconductor die and around the semiconductor die. A first insulating layer is formed over a second surface of the semiconductor die opposite the first surface. A conductive layer is formed over the first insulating layer. An interconnect structure is formed through the encapsulant outside a footprint of the semiconductor die.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a printed circuit board (PCB) with different types of packages mounted to its surface;

FIGS. 2a-2c illustrate further detail of the representative semiconductor packages mounted to the PCB;

FIGS. 3a-3c illustrate a semiconductor wafer with a plurality of semiconductor die separated by saw streets;

FIGS. 4a-4k illustrate a process of forming a vertical interconnect structure for FO-WLCSP;

FIGS. 5a-5b illustrate the FO-WLCSP with vertical interconnect structure having conductive pillars;

FIG. 6 illustrates an alternate embodiment of the FO-WLCSP with vertical interconnect structure;

FIG. 7 illustrates the multi-layer under bump metallization (UBM) for the vertical interconnect structure of the FO-WLCSP;

FIG. 8 illustrates an alternate embodiment of the FO-WLCSP with vertical interconnect structure having conductive pillars and bumps;

FIGS. 9a-9c illustrate the FO-WLCSP with vertical interconnect structure having RDL under the conductive pillars;

FIGS. 10a-10b illustrate another process of forming a vertical interconnect structure for 3-D FO-WLCSP;

FIG. 11 illustrates the FO-WLCSP with vertical interconnect structure having encapsulant over the semiconductor die;

FIG. 12 illustrates the FO-WLCSP with another vertical interconnect structure having encapsulant over the semiconductor die;

FIGS. 13a-13x illustrate another process of forming a vertical interconnect structure for 3-D FO-WLCSP;

FIGS. 14a-14d illustrate a process of mounting a bumped semiconductor device over a 3-D FO-WLCSP with vertical interconnect structure;

FIGS. 15a-15d illustrate another process of forming a vertical interconnect structure for a 3-D FO-WLCSP;

FIGS. 16a-16d illustrate another process of forming a vertical interconnect structure for a 3-D FO-WLCSP;

FIG. 17 illustrates another embodiment of the FO-WLCSP with a vertical interconnect structure;

FIGS. 18a-18b illustrate an alternate embodiment of the FO-WLCSP with a vertical interconnect structure having conductive columns;

FIGS. 19a-19b illustrate another embodiment of a 3-D FO-WLCSP having conductive vias;

FIGS. 20a-20b illustrate a 3-D FO-WLCSP having encapsulant over the semiconductor die;

FIGS. 21a-21c illustrate 3-D FO-WLCSPs having stepped encapsulant;

FIGS. 22a-22c illustrate another embodiment of a 3-D FO-WLCSP including a heat sink or shielding layer;

FIG. 23 illustrates 3-D FO-WLCSPs having a crack stop layer;

FIGS. 24a-24b illustrate a 3-D FO-WLCSP including a horizontally expanded interconnect structure;

FIGS. 25a-25b illustrate another embodiment of a 3-D FO-WLCSP including a horizontally expanded interconnect structure;

FIGS. 26a-26g illustrate another process of forming a vertical interconnect structure for a 3-D FO-WLCSP with a backside protection and balance layer;

FIG. 27 illustrates an alternative embodiment of the 3-D FO-WLCSP including a vertical interconnect structure and multiple semiconductor die;

FIG. 28 illustrates an alternative embodiment of the 3-D FO-WLCSP including a vertical interconnect structure and an optically transmissible layer over the semiconductor die;

FIG. 29 illustrates another embodiment of the 3-D FO-WLCSP including a vertical interconnect structure and an embedded PCB;

FIG. 30 illustrates a stacked 3-D FO-WLCSP with vertical interconnect structure to electrically connect the stacked 3-D FO-WLCSP;

FIG. 31 illustrates another stacked 3-D FO-WLCSP with vertical interconnect structure to electrically connect the stacked 3-D FO-WLCSP; and

FIG. 32 illustrates another stacked 3-D FO-WLCSP with vertical interconnect structure to electrically connect the stacked 3-D FO-WLCSP.

DETAILED DESCRIPTION OF THE DRAWINGS

The present invention is described in one or more embodiments in the following description with reference to the figures, in which like numerals represent the same or similar elements. While the invention is described in terms of the best mode for achieving the invention's objectives, it will be appreciated by those skilled in the art that it is intended to cover alternatives, modifications, and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims and their equivalents as supported by the following disclosure and drawings.

Semiconductor devices are generally manufactured using two complex manufacturing processes: front-end manufacturing and back-end manufacturing. Front-end manufacturing involves the formation of a plurality of die on the surface of a semiconductor wafer. Each die on the wafer contains active and passive electrical components, which are electrically connected to form functional electrical circuits. Active electrical components, such as transistors and diodes, have the ability to control the flow of electrical current. Passive electrical components, such as capacitors, inductors, resistors, and transformers, create a relationship between voltage and current necessary to perform electrical circuit functions.

Passive and active components are formed over the surface of the semiconductor wafer by a series of process steps including doping, deposition, photolithography, etching, and planarization. Doping introduces impurities into the semiconductor material by techniques such as ion implantation or thermal diffusion. The doping process modifies the electrical conductivity of semiconductor material in active devices, transforming the semiconductor material into an insulator,

conductor, or dynamically changing the semiconductor material conductivity in response to an electric field or base current. Transistors contain regions of varying types and degrees of doping arranged as necessary to enable the transistor to promote or restrict the flow of electrical current upon the application of the electric field or base current.

Active and passive components are formed by layers of materials with different electrical properties. The layers can be formed by a variety of deposition techniques determined in part by the type of material being deposited. For example, thin film deposition can involve chemical vapor deposition (CVD), physical vapor deposition (PVD), electrolytic plating, and electroless plating processes. Each layer is generally patterned to form portions of active components, passive components, or electrical connections between components.

The layers can be patterned using photolithography, which involves the deposition of light sensitive material, e.g., photoresist, over the layer to be patterned. A pattern is transferred from a photomask to the photoresist using light. In one embodiment, the portion of the photoresist pattern subjected to light is removed using a solvent, exposing portions of the underlying layer to be patterned. In another embodiment, the portion of the photoresist pattern not subjected to light, the negative photoresist, is removed using a solvent, exposing portions of the underlying layer to be patterned. The remainder of the photoresist is removed, leaving behind a patterned layer. Alternatively, some types of materials are patterned by directly depositing the material into the areas or voids formed by a previous deposition/etch process using techniques such as electroless and electrolytic plating.

Patterning is the basic operation by which portions of the top layers on the semiconductor wafer surface are removed. Portions of the semiconductor wafer can be removed using photolithography, photomasking, masking, oxide or metal removal, photography and stenciling, and microlithography. Photolithography includes forming a pattern in reticles or a photomask and transferring the pattern into the surface layers of the semiconductor wafer. Photolithography forms the horizontal dimensions of active and passive components on the surface of the semiconductor wafer in a two-step process. First, the pattern on the reticle or masks is transferred into a layer of photoresist. Photoresist is a light-sensitive material that undergoes changes in structure and properties when exposed to light. The process of changing the structure and properties of the photoresist occurs as either negative-acting photoresist or positive-acting photoresist. Second, the photoresist layer is transferred into the wafer surface. The transfer occurs when etching removes the portion of the top layers of semiconductor wafer not covered by the photoresist. The chemistry of photoresists is such that the photoresist remains substantially intact and resists removal by chemical etching solutions while the portion of the top layers of the semiconductor wafer not covered by the photoresist is removed. The process of forming, exposing, and removing the photoresist, as well as the process of removing a portion of the semiconductor wafer can be modified according to the particular resist used and the desired results.

In negative-acting photoresists, photoresist is exposed to light and is changed from a soluble condition to an insoluble condition in a process known as polymerization. In polymerization, unpolymerized material is exposed to a light or energy source and polymers form a cross-linked material that is etch-resistant. In most negative resists, the polymers are polyisoprenes. Removing the soluble portions (i.e., the portions not exposed to light) with chemical solvents or developers leaves a hole in the resist layer that corresponds to the

opaque pattern on the reticle. A mask whose pattern exists in the opaque regions is called a clear-field mask.

In positive-acting photoresists, photoresist is exposed to light and is changed from relatively nonsoluble condition to much more soluble condition in a process known as photosolubilization. In photosolubilization, the relatively insoluble resist is exposed to the proper light energy and is converted to a more soluble state. The photosolubilized part of the resist can be removed by a solvent in the development process. The basic positive photoresist polymer is the phenol-formaldehyde polymer, also called the phenol-formaldehyde novolak resin. Removing the soluble portions (i.e., the portions exposed to light) with chemical solvents or developers leaves a hole in the resist layer that corresponds to the transparent pattern on the reticle. A mask whose pattern exists in the transparent regions is called a dark-field mask.

After removal of the top portion of the semiconductor wafer not covered by the photoresist, the remainder of the photoresist is removed, leaving behind a patterned layer. Alternatively, some types of materials are patterned by directly depositing the material into the areas or voids formed by a previous deposition/etch process using techniques such as electroless and electrolytic plating.

Depositing a thin film of material over an existing pattern can exaggerate the underlying pattern and create a non-uniformly flat surface. A uniformly flat surface is required to produce smaller and more densely packed active and passive components. Planarization can be used to remove material from the surface of the wafer and produce a uniformly flat surface. Planarization involves polishing the surface of the wafer with a polishing pad. An abrasive material and corrosive chemical are added to the surface of the wafer during polishing. The combined mechanical action of the abrasive and corrosive action of the chemical removes any irregular topography, resulting in a uniformly flat surface.

Back-end manufacturing refers to cutting or singulating the finished wafer into the individual semiconductor die and then packaging the semiconductor die for structural support and environmental isolation. To singulate the semiconductor die, the wafer is scored and broken along non-functional regions of the wafer called saw streets or scribes. The wafer is singulated using a laser cutting tool or saw blade. After singulation, the individual semiconductor die are mounted to a package substrate that includes pins or contact pads for interconnection with other system components. Contact pads formed over the semiconductor die are then connected to contact pads within the package. The electrical connections can be made with solder bumps, stud bumps, conductive paste, or wirebonds. An encapsulant or other molding material is deposited over the package to provide physical support and electrical isolation. The finished package is then inserted into an electrical system and the functionality of the semiconductor device is made available to the other system components.

FIG. 1 illustrates electronic device **10** having a chip carrier substrate or PCB **12** with a plurality of semiconductor packages mounted on its surface. Electronic device **10** can have one type of semiconductor package, or multiple types of semiconductor packages, depending on the application. The different types of semiconductor packages are shown in FIG. 1 for purposes of illustration.

Electronic device **10** can be a stand-alone system that uses the semiconductor packages to perform one or more electrical functions. Alternatively, electronic device **10** can be a sub-component of a larger system. For example, electronic device **10** can be part of a cellular phone, personal digital assistant (PDA), digital video camera (DVC), or other electronic com-

munication device. Alternatively, electronic device **10** can be a graphics card, network interface card, or other signal processing card that can be inserted into a computer. The semiconductor package can include microprocessors, memories, application specific integrated circuits (ASIC), logic circuits, analog circuits, radio frequency (RF) circuits, discrete devices, or other semiconductor die or electrical components. Miniaturization and weight reduction are essential for the products to be accepted by the market. The distance between semiconductor devices must be decreased to achieve higher density.

In FIG. 1, PCB **12** provides a general substrate for structural support and electrical interconnect of the semiconductor packages mounted on the PCB. Conductive signal traces **14** are formed over a surface or within layers of PCB **12** using evaporation, electrolytic plating, electroless plating, screen printing, or other suitable metal deposition process. Signal traces **14** provide for electrical communication between each of the semiconductor packages, mounted components, and other external system components. Traces **14** also provide power and ground connections to each of the semiconductor packages.

In some embodiments, a semiconductor device has two packaging levels. First level packaging is a technique for mechanically and electrically attaching the semiconductor die to an intermediate carrier. Second level packaging involves mechanically and electrically attaching the intermediate carrier to the PCB. In other embodiments, a semiconductor device may only have the first level packaging where the semiconductor die is mechanically and electrically mounted directly to the PCB.

For the purpose of illustration, several types of first level packaging, including bond wire package **16** and flipchip **18**, are shown on PCB **12**. Additionally, several types of second level packaging, including ball grid array (BGA) **20**, bump chip carrier (BCC) **22**, dual in-line package (DIP) **24**, land grid array (LGA) **26**, multi-chip module (MCM) **28**, quad flat non-leaded package (QFN) **30**, and quad flat package **32**, are shown mounted on PCB **12**. Depending upon the system requirements, any combination of semiconductor packages, configured with any combination of first and second level packaging styles, as well as other electronic components, can be connected to PCB **12**. In some embodiments, electronic device **10** includes a single attached semiconductor package, while other embodiments call for multiple interconnected packages. By combining one or more semiconductor packages over a single substrate, manufacturers can incorporate pre-made components into electronic devices and systems. Because the semiconductor packages include sophisticated functionality, electronic devices can be manufactured using less expensive components and a streamlined manufacturing process. The resulting devices are less likely to fail and less expensive to manufacture resulting in a lower cost for consumers.

FIGS. 2a-2c show exemplary semiconductor packages. FIG. 2a illustrates further detail of DIP **24** mounted on PCB **12**. Semiconductor die **34** includes an active region containing analog or digital circuits implemented as active devices, passive devices, conductive layers, and dielectric layers formed within the die and are electrically interconnected according to the electrical design of the die. For example, the circuit can include one or more transistors, diodes, inductors, capacitors, resistors, and other circuit elements formed within the active region of semiconductor die **34**. Contact pads **36** are one or more layers of conductive material, such as aluminum (Al), copper (Cu), tin (Sn), nickel (Ni), gold (Au), or silver (Ag), and are electrically connected to the circuit elements

formed within semiconductor die **34**. During assembly of DIP **24**, semiconductor die **34** is mounted to an intermediate carrier **38** using a gold-silicon eutectic layer or adhesive material such as thermal epoxy or epoxy resin. The package body includes an insulative packaging material such as polymer or ceramic. Conductor leads **40** and bond wires **42** provide electrical interconnect between semiconductor die **34** and PCB **12**. Encapsulant **44** is deposited over the package for environmental protection by preventing moisture and particles from entering the package and contaminating semiconductor die **34** or bond wires **42**.

FIG. **2b** illustrates further detail of BCC **22** mounted on PCB **12**. Semiconductor die **46** is mounted over carrier **48** using an underfill or epoxy-resin adhesive material **50**. Bond wires **52** provide first level packaging interconnect between contact pads **54** and **56**. Molding compound or encapsulant **60** is deposited over semiconductor die **46** and bond wires **52** to provide physical support and electrical isolation for the device. Contact pads **64** are formed over a surface of PCB **12** using a suitable metal deposition process such as electrolytic plating or electroless plating to prevent oxidation. Contact pads **64** are electrically connected to one or more conductive signal traces **14** in PCB **12**. Bumps **66** are formed between contact pads **56** of BCC **22** and contact pads **64** of PCB **12**.

In FIG. **2c**, semiconductor die **18** is mounted face down to intermediate carrier **76** with a flipchip style first level packaging. Active region **78** of semiconductor die **18** contains analog or digital circuits implemented as active devices, passive devices, conductive layers, and dielectric layers formed according to the electrical design of the die. For example, the circuit can include one or more transistors, diodes, inductors, capacitors, resistors, and other circuit elements within active region **78**. Semiconductor die **18** is electrically and mechanically connected to carrier **76** through bumps **80**.

BGA **20** is electrically and mechanically connected to PCB **12** with a BGA style second level packaging using bumps **82**. Semiconductor die **18** is electrically connected to conductive signal traces **14** in PCB **12** through bumps **80**, signal lines **84**, and bumps **82**. A molding compound or encapsulant **86** is deposited over semiconductor die **18** and carrier **76** to provide physical support and electrical isolation for the device. The flipchip semiconductor device provides a short electrical conduction path from the active devices on semiconductor die **18** to conduction tracks on PCB **12** in order to reduce signal propagation distance, lower capacitance, and improve overall circuit performance. In another embodiment, the semiconductor die **18** can be mechanically and electrically connected directly to PCB **12** using flipchip style first level packaging without intermediate carrier **76**.

FIG. **3a** shows a semiconductor wafer **90** with a base substrate material **92**, such as silicon, germanium, gallium arsenide, indium phosphide, or silicon carbide, for structural support. A plurality of semiconductor die or components **112** is formed on wafer **90** separated by a non-active, inter-die wafer area or saw street **94** as described above. Saw street **94** provides cutting areas to singulate semiconductor wafer **90** into individual semiconductor die **112**.

FIG. **3b** shows a cross-sectional view of a portion of semiconductor wafer **90**. Each semiconductor die **112** has a back surface **96** and active surface **97** containing analog or digital circuits implemented as active devices, passive devices, conductive layers, and dielectric layers formed within the die and electrically interconnected according to the electrical design and function of the die. For example, the circuit may include one or more transistors, diodes, and other circuit elements formed within active surface **97** to implement analog circuits or digital circuits, such as digital signal processor (DSP),

ASIC, memory, or other signal processing circuit. Semiconductor die **112** may also contain integrated passive devices (IPDs), such as inductors, capacitors, and resistors, for RF signal processing. In one embodiment, semiconductor die **112** is a flipchip type device.

An electrically conductive layer **98** is formed over active surface **97** using PVD, CVD, electrolytic plating, electroless plating process, or other suitable metal deposition process. Conductive layer **98** can be one or more layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable electrically conductive material. Conductive layer **98** operates as contact pads electrically connected to the circuits on active surface **97**. Conductive layer **98** can be formed as contact pads disposed side-by-side a first distance from the edge of semiconductor die **112**, as shown in FIG. **3b**. Alternatively, conductive layer **98** can be formed as contact pads that are offset in multiple rows such that a first row of contact pads is disposed a first distance from the edge of the die, and a second row of contact pads alternating with the first row is disposed a second distance from the edge of the die.

An electrically conductive bump material is deposited over contact pads **98** using an evaporation, electrolytic plating, electroless plating, ball drop, or screen printing process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to contact pads **98** using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form balls or bumps **114**. In some applications, bumps **114** are reflowed a second time to improve electrical contact to contact pads **98**. Bumps **114** can also be compression bonded or thermocompression bonded to contact pads **98**. Bumps **114** represent one type of interconnect structure that can be formed over contact pads **98**. The interconnect structure can also use stud bump, micro bump, or other electrical interconnect.

In FIG. **3c**, semiconductor wafer **90** is singulated through saw street **94** using a saw blade or laser cutting tool **99** into individual semiconductor die **112**.

FIGS. **4a-4k** illustrate, in relation to FIGS. **1** and **2a-2c**, a process of forming a vertical interconnect structure for 3-D FO-WLCSP. In FIG. **4a**, a substrate or wafer **100** contains dummy or sacrificial base material such as silicon (Si), polymer, polymer composite, metal, ceramic, glass, glass epoxy, beryllium oxide, or other suitable low-cost, rigid material or bulk semiconductor material for structural support.

The interface layer **102** can be temporary bonding film or etch-stop layer. The temporary bonding film can be either heat or light releasable material. The etch-stop layer can be silicon dioxide (SiO₂), silicon nitride (Si₃N₄), silicon oxynitride (SiON), organic film, or metal film with wet etching selectivity. The interface layer **102** is deposited using lamination, PVD, CVD, printing, spin coating, spray coating, sintering, or thermal oxidation. The interface layer **102** is releasable in a later step by light or heat. Alternatively, interface layer **102** can be removed by an etching process after removing carrier **100**. In one embodiment, interface layer **102** is SiO₂/Si₃N₄ thin film and acts as an etch-stop.

An electrically conductive layer **104** is formed over interface layer **102** using a deposition and patterning process to form individual portions or sections **104a-104d**. FIG. **4b** shows a top or plan view of conductive layer **104a-104d**, with conductive layer **104a** being electrically isolated or partially isolated from conductive layer **104b-104d** by gap **106** which exposes interface layer **102**. Conductive layer **104** can be one or more layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable

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electrically conductive material. The deposition of conductive layer **104** uses PVD, CVD, sputtering, electrolytic plating, electroless plating, metal evaporation, metal sputtering, or other suitable metal deposition process. In one embodiment, conductive layer **104a** is a solid film for conducting current for later formed conductive pillars. Conductive layer **104b-104d** includes a plated seed layer and under bump metallization (UBM) pads containing multiple layers of selectively plated Ni/Au, titanium (Ti)/Cu, titanium tungsten (TiW)/Cu, Ti/Cu/nickel vanadium (NiV)/Cu, or their combination. UBM pads **104b-104d** provide bondable pads for bonding with bumps **114**, and may further provide a barrier to diffusion and a seed layer for wettability.

In FIG. **4c**, a photoresist layer **108** is deposited over interface layer **102** and conductive layer **104**. A portion of photoresist layer **108** is exposed and removed by an etching development process. Conductive pillars or posts **110** are formed in the removed portion of photoresist **108** over conductive layer **104a** using selective plating or other suitable process. Conductive pillars **110** are Cu, Al, tungsten (W), Au, solder, or other suitable electrically conductive material. In one embodiment, conductive pillars **110** are formed by plating Cu in the patterned areas of photoresist **108**. In one embodiment, conductive pillars **110** have a height ranging from 2-120 micrometers (μm). Photoresist **108** is stripped away leaving behind individual conductive pillars **110**. In another embodiment, conductive pillars **110** can be replaced with solder balls or stud bumps.

In FIG. **4d**, semiconductor die **112** from FIGS. **3a-3c** are mounted to UBM pads **104b-104d** with bumps **114** in a flip-chip arrangement such that the active surface of semiconductor die **112** is oriented toward carrier **100**. Alternatively, bumps or interconnects **114** are formed over UBM pads **104b-104d** rather than over contact pads **98** such that semiconductor die **112** is mounted to bumps or interconnects **114** when the semiconductor die is mounted over the UBM pads. In another embodiment, passive components are mounted to UBM pads **104b-104d**. Accordingly, the same conductive layer **104** operates for both flipchip bonding placement and conductive pillar plating.

FIG. **4e** shows an encapsulant or molding compound **116** deposited over semiconductor die **112**, conductive layer **104**, interface layer **102**, and around conductive pillars **110** using a paste printing, compressive molding, transfer molding, liquid encapsulant molding, vacuum lamination, or other suitable applicator. Encapsulant **116** can be polymer composite material, such as epoxy resin with filler, epoxy acrylate with filler, or polymer with proper filler. Encapsulant **116** is non-conductive and environmentally protects the semiconductor device from external elements and contaminants. Encapsulant **116** has a coefficient of thermal expansion (CTE) that is adjusted to match that of the base semiconductor material, e.g., Si, with a high glass transition temperature (T_g) in the range of 100 to 300 degrees Celsius ($^{\circ}\text{C}$.) to reduce warpage. The CTE of encapsulant **116** can be adjusted using a filler such as a powder, fiber, or cloth additive. A suitable encapsulant material is generally characterized by good thermal conductivity similar to Si, low-shrinkage, high-resistivity of greater than 1.0 kohm-cm, low-dielectric constant of less than 3.5, and low-loss tangent of less than 0.02.

Encapsulant **116** undergoes grinding or plasma etching to expose the top surface of conductive pillars **110** and semiconductor die **112**. Alternatively, encapsulant **116** is deposited with a partially exposed molding technology such that encapsulant **116** does not cover the top surface of conductive pillars **110** and semiconductor die **112**. In either instance, conductive pillars **110** represent a through molding interconnect (TMI)

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structure. A height of the exposed surface of conductive pillars **110** is less than a height of a backside surface of semiconductor die **112**. As a result, a height of encapsulant **116** adjacent to the backside surface of semiconductor die **112** is greater than a height of encapsulant **116** formed over carrier **100** and in a periphery of conductive pillars **110** outside a footprint of semiconductor die **112**. A portion of a top surface of encapsulant **116** includes a tapered or sloped profile that extends from a first height of encapsulant **116** formed in a periphery of conductive pillars **110** to a backside surface of semiconductor die **112** at a second height. The second height is greater than the first height. In one embodiment, the difference between the first height and the second height is in a range of 10-200 μm . The difference between the first height and the second height can be changed by removing a portion of the backside surface of semiconductor die **112** and a portion of encapsulant **116** in a periphery of the backside of the semiconductor die with backgrinding or other suitable process.

In FIG. **4f**, an insulation or passivation layer **118** is formed over conductive pillars **110**, encapsulant **116**, and semiconductor die **112** using PVD, CVD, screen printing, spin coating, spray coating, sintering or thermal oxidation. Insulation layer **118** contains one or more layers of SiO_2 , Si_3N_4 , SiON , tantalum pentoxide (Ta_2O_5), aluminum oxide (Al_2O_3), polyimide, benzocyclobutene (BCB), polybenzoxazoles (PBO), or other material having similar insulating and structural properties. In one embodiment, insulation layer **118** is a photosensitive dielectric polymer low-cured at less than 200 $^{\circ}\text{C}$. Insulation layer **118** is conformally applied to, follows the contours of, and uniformly covers conductive pillars **110**, encapsulant **116**, and semiconductor die **112**. In one embodiment, a portion of insulation layer **118** is removed by etching or other suitable process to expose the top surface of conductive pillars **110**. The insulation layer **118** is used to planarize the wafer topography and is optional.

An electrically conductive layer **120** is formed over conductive pillars **110** and insulation layer **118** using a patterning and metal deposition process such as printing, PVD, CVD, sputtering, electrolytic plating, electroless plating, metal evaporation, metal sputtering, or other suitable metal deposition process. Conductive layer **120** is one or more layers of Al, Cu, Sn, Ni, Au, Ag, Ti, or other suitable electrically conductive material. In one embodiment, conductive layer **120** is a multi-layer RDL structure containing Ti/Cu or Ti/Al alloy. Conductive layer **120** follows the contour of insulation layer **118**, the openings in insulation layer **118** over conductive pillars **110**, and portions of conductive pillars **110** exposed by the openings in insulation layer **118**. Conductive layer **120** operates as an RDL to extend electrical connection with respect to conductive pillar **110**.

An insulation or passivation layer **122** is formed over insulation layer **118** and conductive layer **120** using PVD, CVD, screen printing, spin coating, spray coating, sintering or thermal oxidation. Insulation layer **122** contains one or more layers of SiO_2 , Si_3N_4 , SiON , Ta_2O_5 , Al_2O_3 , polyimide, BCB, PBO, or other material having similar insulating and structural properties. In one embodiment, insulation layer **122** is a photosensitive dielectric polymer low-cured at less than 200 $^{\circ}\text{C}$. Insulation layer **122** is formed over insulation layer **118** and conductive layer **120** to planarize the wafer topography and protect the conductive layer. A portion of insulation layer **122** is removed by etching or other suitable process to expose conductive layer **120** for package level interconnection. Additional insulation layers and conductive layers can be added to the device structure as needed for interconnect functionality.

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In FIG. 4g, carrier **100** and interface layer **102** are removed by chemical etching, mechanical peel-off, chemical mechanical planarization (CMP), mechanical grinding, thermal bake, laser scanning, or wet stripping. An optional protective layer **124** is formed over conductive layer **120** and insulation layer **122** either before or after carrier and interface layer removal. Conductive layer **104a-104d** remains as shown in FIG. 4b during carrier and interface layer removal. A portion of conductive layer **104a** is then removed by selective patterning and wet-etching or other suitable process to form a design pattern including interconnect lines **126** and pads **128** as shown in a cross-sectional view in FIG. 4h and a plan view in FIG. 4i. Conductive layer **104** is patterned such that UBM pads **104b-104d**, interconnect lines **126**, and pads **128** together with later formed bumps will provide electrical connection within the semiconductor device and provide next level electrical connection to points outside the semiconductor device. In one embodiment, the removal of portions of conductive layer **104a** further forms additional circuit components, such as an inductor.

In FIG. 4h, an insulation or passivation layer **130** is formed over an active surface of semiconductor die **112**, conductive layer **104**, and encapsulant **116** using PVD, CVD, screen printing, spin coating, spray coating, sintering or thermal oxidation. Insulation layer **130** contains one or more layers of SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, polyimide, BCB, PBO, or other material having similar insulating and structural properties. In one embodiment, insulation layer **130** is a photosensitive dielectric polymer low-cured at less than 200° C. Insulation layer **130** is formed over and protects conductive layer **104**. A portion of insulation layer **130** is removed by etching or other suitable process to expose a portion of conductive layer **104**.

FIG. 4i shows a plan view of the semiconductor device including conductive layer **104**, UBM pads **104b-104d**, interconnect lines **126**, pads **128**, and insulation layer **130** configured such that later formed bumps will provide electrical connection within the semiconductor device and provide next level electrical connection to points outside the semiconductor device.

FIG. 4j shows further detail of area **132** from FIG. 4h including conductive layer **104a**, conductive layer **104d**, and insulation layer **130**. Conductive layers **104a-104d** each include stacked top wetting layer **134**, barrier layer **136**, and bottom wetting layer **138**, such as Cu/NiV/Cu, Cu/TiW/Cu, or Cu/Ti/Cu. Adhesion layer **140** is formed between the stacked wetting and barrier layers, and insulation layer **130**. In one embodiment, adhesion layer **140** is a Ti film layer. Alternatively, adhesion layer **140** is TiW, Al, or chromium (Cr). The insulation layer **130** is formed over conductive layers **104a-104d**. A portion of adhesion layer **140** that is exposed by the openings formed in insulation layer **130** is removed by dry etching, wet etching, or other suitable process to expose bottom wetting layer **138** outside a footprint of insulation layer **130**.

FIG. 4k, similar to FIG. 4j, shows an alternate embodiment of area **132** from FIG. 4h including conductive layer **104a**, conductive layer **104d**, and insulation layer **130**. Conductive layers **104a-104d** include a multiple metal stack with top wetting layer **142**, barrier layer **144**, optional bottom wetting layer **146**, and adhesion layer **148**. Adhesion layer **148** includes a Ti, TiW film, or other suitable material. Conductive layer **150** is formed over adhesion layer **148** using a patterning and metal deposition process such as printing, PVD, CVD, sputtering, electrolytic plating, electroless plating, metal evaporation, metal sputtering, or other suitable metal deposition process. Conductive layer **150** can be one or more

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layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable electrically conductive material. In one embodiment, conductive layer **150** is plated Cu and is formed by using conductive layer **104** as seed layer for selective plating. A portion of conductive layer **150** is removed by etching or other suitable process to form an inductor. A portion of adhesion layer **148** can be removed by dry etching, wet etching, or other suitable process to expose bottom wetting layer **146** either before or after the formation of conductive layer **150**. In either instance, the portion of adhesion layer **148** is removed before the formation of insulation layer **130** over conductive layer **150**.

FIG. 5a shows a 3-D FO-WLCSP from FIGS. 4a-4k with an electrically conductive bump material deposited over conductive layer **104a-104d** using an evaporation, electrolytic plating, electroless plating, ball drop, or screen printing process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to conductive layer **104a-104d** using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form spherical balls or bumps **152** and **154**. In some applications, bumps **152** and **154** are reflowed a second time to improve electrical contact to conductive layer **104a-104d**. The bumps can also be compression bonded to conductive layer **104a-104d**. Bumps **152** act as a bridge between interconnect lines **126** and UBM pads **104b-104d**, see e.g., FIGS. 4i and 5b. Bumps **154** are made higher than bumps **152** for next level interconnect without electrically shorting bumps **152**. Bumps **152** and **154** represent one type of interconnect structure that can be formed over conductive layer **104a-104d**. The interconnect structure can also use bond wires, 3-D interconnects, conductive paste, stud bump, micro bump, or other electrical interconnect. The 3-D FO-WLCSP provides electrical connection for semiconductor die **112** to external devices through a vertical interconnect structure including conductive layer **104**, TMI conductive pillars **110**, conductive layer **120**, and bumps **152** and **154**.

FIG. 6 shows an alternate embodiment of a 3-D FO-WLCSP similar to the 3-D FO-WLCSP from FIGS. 4a-4k, with similar elements having the same numbers. In FIG. 6, conductive layer **156** is formed over conductive layer **104** and encapsulant **116** using a patterning and metal deposition process such as printing, PVD, CVD, sputtering, electrolytic plating, electroless plating, metal evaporation, metal sputtering, or other suitable metal deposition process. Conductive layer **156** can be one or more layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable electrically conductive material. Conductive layer **156** is formed over conductive layer **104** and encapsulant **116** after a carrier and interface layer similar to carrier **100** and interface **102** from FIGS. 4a-4f are removed. Conductive layer **156** provides an electrical path between bumps **114** of semiconductor die **112**, conductive pillars **110**, and later formed bumps for next level interconnect. Conductive layers **104** and **156** are formed or deposited together in the same process step. Portions of conductive layers **104** and **156** are then removed in two separate steps by patterning and etching or other suitable process. A portion of conductive layer **104** is removed before the formation of conductive pillars **110**. A portion of conductive layer **156** is removed after the carrier and interface layer are removed such that the remaining portion of conductive layer **156** is a UBM for later formed bumps. The remaining portion is also an RDL that provides electrical interconnect between later formed bumps, conductive pillars **110**, and semiconductor die **112**.

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An insulation or passivation layer **158** is formed over conductive layer **156** and encapsulant **116** using PVD, CVD, screen printing, spin coating, spray coating, sintering or thermal oxidation. Insulation layer **158** contains one or more layers of SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, polyimide, BCB, PBO, or other material having similar insulating and structural properties. In one embodiment, insulation layer **158** is a photosensitive dielectric polymer low-cured at less than 200° C. Insulation layer **158** is conformally applied to, follows the contours of, and protects, conductive layer **156** and encapsulant **116**. A portion of insulation layer **158** is removed by etching or other suitable process to expose a portion of conductive layer **156** for subsequent electrical interconnect.

An electrically conductive bump material is deposited over conductive layer **156** using an evaporation, electrolytic plating, electroless plating, ball drop, or screen printing process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to conductive layer **156** using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form spherical balls or bumps **160**. In some applications, bumps **160** are reflowed a second time to improve electrical contact to conductive layer **156**. The bumps can also be compression bonded to conductive layer **156**. Bumps **160** represent one type of interconnect structure that can be formed over conductive layer **156**. The interconnect structure can also use bond wires, 3-D interconnects, conductive paste, stud bump, micro bump, or other electrical interconnect. Bumps **160** of the 3-D FO-WLCSP provide electrical connection for semiconductor die **112** to external devices through a vertical interconnect structure including conductive layers **104** and **156**, TMI conductive pillars **110**, and conductive layer **120**.

FIG. 7 shows further detail of area **162** from FIG. 6 including conductive layers **104** and **156**. Conductive layers **104a-104d** each include a multiple metal stack with top wetting layer **163** and barrier layer **164**. In one embodiment, wetting layer **163** is Cu and barrier layer **164** is NiV or Ni. Similarly, conductive layer **156** also includes a multiple metal stack with an optional middle adhesion layer **165**, optional barrier layer **166**, bottom wetting layer **167**, and bottom adhesive layer **168**. In one embodiment, adhesion layer **165** is Ti or TiW, barrier layer **166** is NiV or Ni, wetting layer **167** is Cu, and adhesive layer **168** is Ti. Conductive layers **104** and **156** are formed as separate layers, or alternatively, the conductive layers are formed or deposited together in the same process step. When conductive layers **104** and **156** are formed as separate layers, conductive layer **104** is formed and patterned before the formation of conductive pillars **110**, and conductive layer **156** is formed after the removal of a temporary carrier and interface layer similar to carrier **100** and interface layer **102** shown in FIGS. 4a-4f. When conductive layers **104** and **156** are formed in the same process step, portions of the conductive layers are removed in two separate steps by patterning and etching or other suitable process. A portion of conductive layer **104** is removed from wetting layer **163** and barrier layer **164** before the formation of conductive pillars **110**. A portion of conductive layer **156** is removed from adhesive layer **168** such that the remaining portion of conductive layer **156** is a UBM for later formed bumps. The remaining portion of conductive layer **156** is also an RDL that provides electrical interconnect between later formed bumps, conductive pillars **110**, and semiconductor die **112**. Conductive

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layer **156** is configured as a UBM and RDL after the carrier and interface layer are removed.

FIG. 8 shows an alternate embodiment of an interconnect structure for a 3-D FO-WLCSP similar to the 3-D FO-WLCSP from FIGS. 4a-4k. An electrically conductive layer **170**, similar to conductive layer **104** shown in FIGS. 4a-4k, is formed over a carrier and interface layer to form individual portions or sections **170a-170d**. Conductive layer **170a** is electrically isolated from conductive layers **170b-170d**. In one embodiment, conductive layers **170b-170d** include a plated seed layer and UBM pads containing multiple layers of selectively plated Ni/Au, Ti/Cu, or Ti/Cu/NiV/Cu.

Conductive pillars or posts **176**, similar to conductive posts **110** in FIG. 4c, are formed over conductive layer **170a**. Semiconductor die **172**, similar to semiconductor die **112** in FIG. 4d, are mounted to UBM pads **170b-170d** with bumps **174** in a flipchip arrangement. In another embodiment, passive components can be mounted to UBM pads **170b-170d**.

A first encapsulant or molding compound **178**, similar to encapsulant **116** in FIG. 4e, is deposited over semiconductor die **172**, over conductive layer **170**, over a temporary carrier and interface layer similar to carrier **100** and interface layer **102**, and around conductive pillars **176**. Encapsulant **178** is deposited using a paste printing, compressive molding, transfer molding, liquid encapsulant molding, vacuum lamination, or other suitable applicator. Encapsulant **178** can be polymer composite material, such as epoxy resin with filler, epoxy acrylate with filler, or polymer with proper filler. Encapsulant **178** is non-conductive and environmentally protects the semiconductor device from external elements and contaminants. Encapsulant **178** has a CTE that is adjusted to match that of the base semiconductor material, e.g., Si, with a high T_g in the range of 100° C. to 300° C. to reduce warpage. The CTE of encapsulant **178** can be adjusted using a filler such as a powder, fiber, or cloth additive. A suitable encapsulant material is generally characterized by good thermal conductivity similar to Si, low-shrinkage, high-resistivity of greater than 1.0 kohm-cm, low-dielectric constant of less than 3.5, and low-loss tangent of less than 0.02.

Encapsulant **178** undergoes grinding or plasma etching to expose the top surface of conductive pillars **176** and semiconductor die **172**. Alternatively, encapsulant **178** is deposited with a partially exposed molding technology such that encapsulant **178** does not cover the top surface of conductive pillars **176** and semiconductor die **172**. In either instance, conductive pillars **176** represent a TMI structure. A height of the exposed surface of conductive pillars **176** is less than a height of a backside surface of semiconductor die **172**. As a result, a height of encapsulant **178** adjacent to the backside surface of semiconductor die **172** is greater than a height of encapsulant **178** formed over the carrier and in a periphery of conductive pillars **176** outside a footprint of semiconductor die **172**. A portion of a top surface **179** of encapsulant **178** includes a tapered or sloped profile that extends from a first height of encapsulant **178** formed in a periphery of conductive pillars **176** to a backside surface of semiconductor die **172** at a second height. The second height is greater than the first height. In one embodiment, the difference between the first height and the second height is in a range of 10-200 μm. The difference between the first height and the second height can be changed by removing a portion of the backside surface of semiconductor die **172** and a portion of encapsulant **178** in a periphery of the backside of semiconductor die with back-grinding or other suitable process.

An electrically conductive bump material is deposited over conductive pillars **176** using an evaporation, electrolytic plat-

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ing, electroless plating, ball drop, or screen printing process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to conductive pillars **176** using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form spherical balls or bumps **180**. In some applications, bumps **180** are reflowed a second time to improve electrical contact to conductive pillars **176**. The bumps can also be compression bonded to conductive pillars **176**. Bumps **180** represent one type of interconnect structure that can be formed over conductive pillars **176**. The interconnect structure can also use conductive paste, stud bump, micro bump, or other electrical interconnect. Accordingly, bumps **180** are formed over, and are electrically connected to, conductive pillars **176** to form a TMI structure with increased height or standoff.

A second encapsulant or molding compound **181** is deposited over first encapsulant **178**, over semiconductor die **172**, and around bumps **180** using a paste printing, compressive molding, transfer molding, liquid encapsulant molding, vacuum lamination, or other suitable applicator. Encapsulant **181** can be polymer composite material, such as epoxy resin with filler, epoxy acrylate with filler, or polymer with proper filler. Encapsulant **181** is non-conductive and environmentally protects the semiconductor device from external elements and contaminants. Encapsulant **181** has a CTE that is adjusted to match that of the base semiconductor material, e.g., Si, with a high T_g in the range of 100° C. to 300° C. to reduce warpage. The CTE of encapsulant **181** can be adjusted using a filler such as a powder, fiber, or cloth additive. A suitable encapsulant material is generally characterized by good thermal conductivity similar to Si, low-shrinkage, high-resistivity of greater than 1.0 kohm-cm, low-dielectric constant of less than 3.5, and low-loss tangent of less than 0.02.

Encapsulant **181** includes a first or bottom surface **182** that is conformally applied to, and follows the contours of, the top surface **179** of encapsulant **178** including the tapered or sloped profile that extends from a first height in a periphery of conductive pillars **176** to a backside surface of semiconductor die **172** at a second height. Encapsulant **181** also includes a second or top surface **183** formed opposite the first or bottom surface **182**. Second or top surface **183** is planar and does not parallel the contour of the first or bottom surface **182**. In one embodiment, encapsulant **181** is deposited with a partially exposed molding technology such that the second or top surface **183** of encapsulant **181** does not cover a top surface or portion of bumps **180**. Alternatively, the second or top surface **183** of encapsulant **181** does cover a top surface or portion of bumps **180**, and encapsulant **181** undergoes grinding or plasma etching to remove a portion of encapsulant **181** to expose the top surface or portion of bumps **180**. In either instance, bumps **180** are exposed as part of a TMI structure having increased height or standoff with respect to a TMI structure including only conductive pillars **176**.

An electrically conductive layer **184** is formed over bumps **180** and encapsulant **181** using a patterning and metal deposition process such as printing, PVD, CVD, sputtering, electrolytic plating, electroless plating, metal evaporation, metal sputtering, or other suitable metal deposition process. Conductive layer **184** is one or more layers of Al, Cu, Sn, Ni, Au, Ag, Ti, or other suitable electrically conductive material. In one embodiment, conductive layer **184** is a multi-layer RDL structure containing Ti/Cu or Ti/Al alloy. Conductive layer **184** is conformally applied to, and follows the contour of, a

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top surface or portion of bumps **180** and second or top surface **183** of encapsulant **181**. Conductive layer **184** operates as an RDL to extend electrical connection with respect to bump **180** and conductive pillar **176**.

An insulation or passivation layer **186** is formed over second encapsulant **181** and conductive layer **184** using PVD, CVD, screen printing, spin coating, spray coating, sintering or thermal oxidation. Insulation layer **186** contains one or more layers of SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, polyimide, BCB, PBO, or other material having similar insulating and structural properties. In one embodiment, insulation layer **186** is a photosensitive dielectric polymer low-cured at less than 200° C. Insulation layer **186** is formed over encapsulant **181** and conductive layer **184** to planarize the wafer topography and protect the conductive layer. A portion of insulation layer **186** is removed by etching or other suitable process to expose conductive layer **184** for package level interconnection. Additional insulation layers and conductive layers can be added to the device structure as needed for interconnect functionality.

The carrier and interface layer, similar to carrier **100** and interface layer **102** in FIG. 4g, are removed by chemical etching, mechanical peel-off, CMP, mechanical grinding, thermal bake, laser scanning, or wet stripping. A portion of conductive layer **170a** is then removed by selective patterning and wet-etching or other suitable process to form a design pattern including interconnect lines and pads similar to interconnect lines **126** and pads **128** shown in FIG. 4h and FIG. 4i. Conductive layer **170a** can also be patterned to form additional circuit components, such as an inductor.

An insulation or passivation layer **188**, similar to insulation layer **130** in FIG. 4h, is formed over an active surface of semiconductor die **172**, conductive layer **170**, and encapsulant **178**. Insulation layer **188** is formed over and protects conductive layer **170**. A portion of insulation layer **188** is removed by etching or other suitable process to expose a portion of conductive layer **170**.

An electrically conductive bump material is deposited over conductive layer **170a-170d** to form spherical balls or bumps **190** and **192**, similar to the process of forming bumps **152** and **154** shown in FIG. 5a. Bumps **190** act as a bridge between interconnect lines and UBM pads, similar to interconnect lines **126** and UBM pads **128** in FIGS. 4i and 5b. Bumps **192** are made larger than bumps **190** for next level interconnect without electrically shorting bumps **190**. Bumps **190** and **192** represent one type of interconnect structure that can be formed over conductive layer **170a-170d**. The interconnect structure can also use bond wires, 3-D interconnects, conductive paste, stud bump, micro bump, or other electrical interconnect. The 3-D FO-WLCSP provides electrical connection for semiconductor die **172** to external devices through a vertical interconnect structure including conductive layer **170**, TMI conductive pillars **176**, conductive layer **184**, and bumps **180**, **190**, and **192**.

FIGS. 9a-9c show an alternate embodiment of an interconnect structure for a 3-D FO-WLCSP similar to the 3-D FO-WLCSP from FIG. 6. FIG. 9a differs from FIG. 6 with the inclusion of conductive layer **218**, which is discussed in more detail below. In FIG. 9a, an electrically conductive layer **200**, similar to conductive layer **104** shown in FIG. 6, is formed over a carrier and interface layer to form individual portions or sections **200a-200d**. Individual portions or sections **200a-200d** are shown in plan view in FIG. 9b. Conductive layer **200a** is electrically isolated from conductive layers **200b-200d** by gap **203**. In one embodiment, conductive layers

200b-200d include a plated seed layer and UBM pads containing multiple layers of selectively plated Ni/Au, Ti/Cu, or Ti/Cu/NiV/Cu.

Conductive pillars or posts **206**, similar to conductive posts **110** in FIG. **6**, are formed over conductive layer **200a**. Semiconductor die **202**, similar to semiconductor die **112** in FIG. **6**, are mounted to UBM pads **200b-200d** with bumps **204** in a flipchip arrangement. In another embodiment, passive components can be mounted to UBM pads **200b-200d**. Encapsulant **208**, insulation layer **210**, conductive layer **212**, and insulation layer **214** shown in FIG. **9a** are analogous to encapsulant **116**, insulation layer **118**, conductive layer **120**, and insulation layer **122**, respectively, as shown in FIGS. **4a-4k** and FIG. **6**.

After forming or depositing material over the carrier and interface layer, e.g., providing encapsulant **208**, insulation layer **210**, conductive layer **212**, and insulation layer **214**, the carrier and interface layer, similar to carrier **100** and interface layer **102** in FIG. **4g**, are removed by chemical etching, mechanical peel-off, CMP, mechanical grinding, thermal bake, laser scanning, or wet stripping. Conductive layers **200a-200d** remain as shown in FIG. **9b** during carrier and interface layer removal. A portion of conductive layer **200a** is then removed by selective patterning and wet-etching or other suitable process to form a design pattern including interconnect lines and pads shown in the cross-sectional view of FIG. **9a** and the plan view of FIG. **9c**. Conductive layer **200a** can also be patterned to form additional circuit components, such as an inductor.

A conductive layer **218** is formed over conductive layer **200** and encapsulant **208** using a patterning and metal deposition process such as printing, PVD, CVD, sputtering, electrolytic plating, electroless plating, metal evaporation, metal sputtering, or other suitable metal deposition process. Conductive layer **218** can be one or more layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable electrically conductive material. Conductive layer **218** is formed over conductive layer **200** and encapsulant **208** after a portion of conductive layer **200a** is removed to form the interconnect lines **216** and pads shown in FIG. **9c**. Conductive layer **218** provides an electrical path between bumps **204** of semiconductor die **202**, conductive pillars **206**, and later formed bumps for next level interconnect. Thus, conductive layer **218** provides interconnection among semiconductor die **202** and points external to the semiconductor die rather than using bumps, such as bumps **152** shown in FIG. **5a** to provide electrical interconnect. Accordingly, conductive layers **200** and **218** shown in FIG. **9a** are formed in different process steps. Conductive layer **200** is formed over the carrier and interface layer. Conductive layer **218** is formed over conductive layer **200** after the removal of the carrier and interface layer. Thus, the forming of conductive layer **218** in FIG. **9** differs from the formation of conductive layer **156** from FIG. **6** because conductive layer **156** is formed over the carrier and interface layer with, and in the same process step as, conductive layer **104**.

FIG. **9a** further shows an insulation or passivation layer **220** formed over conductive layer **218** and encapsulant **208** using PVD, CVD, screen printing, spin coating, spray coating, sintering or thermal oxidation. Insulation layer **220** contains one or more layers of SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, polyimide, BCB, PBO, or other material having similar insulating and structural properties. In one embodiment, insulation layer **220** is a photosensitive dielectric polymer low-cured at less than 200° C. Insulation layer **220** is conformally applied to, follows the contours of, and protects, conductive layer **218** and encapsulant **208**. A portion of insulation

layer **220** is removed by etching or other suitable process to expose a portion of conductive layer **218** for subsequent electrical interconnect.

An electrically conductive bump material is deposited over conductive layer **218** using an evaporation, electrolytic plating, electroless plating, ball drop, or screen printing process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to conductive layer **218** using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form spherical balls or bumps **222**. In some applications, bumps **222** are reflowed a second time to improve electrical contact to conductive layer **218**. The bumps can also be compression bonded to conductive layer **218**. Bumps **222** represent one type of interconnect structure that can be formed over conductive layer **218**. The interconnect structure can also use bond wires, 3-D interconnects, conductive paste, stud bump, micro bump, or other electrical interconnect. Bumps **222** of the 3-D FO-WLCSP provide electrical connection for semiconductor die **202** to external devices through a vertical interconnect structure including conductive layers **200** and **218**, TMI conductive pillars **206**, and conductive layer **212**.

FIGS. **10a-10b** illustrate another process of forming an interconnect structure for 3-D FO-WLCSP. In FIG. **10a**, a substrate or wafer **230** contains dummy or sacrificial base material such as Si, polymer, polymer composite, metal, ceramic, glass, glass epoxy, beryllium oxide, or other suitable low-cost, rigid material or bulk semiconductor material for structural support.

An interface layer **232** is deposited over carrier **230**. The interface layer **232** can be temporary bonding film or etch-stop layer. The temporary bonding film can be either heat or light releasable material. The etch-stop layer can be SiO₂, Si₃N₄, SiON, organic film, or metal film. The interface layer **232** is deposited using lamination, PVD, CVD, printing, spin coating, spray coating, sintering or thermal oxidation. In one embodiment, interface layer **232** is SiO₂/Si₃N₄ thin film and acts as an etch-stop.

A photoresist layer is deposited over interface layer **232**. A portion of the photoresist is exposed and removed by an etching process. Conductive pillars or posts **234** are formed in the removed portion of the photoresist using a photolithographic process. Conductive pillars or posts **234** are formed in the removed portion of the photoresist over interface layer **232** using selective plating or other suitable process. Conductive pillars **234** can be Cu, Al, W, Au, solder, or other suitable electrically conductive material. In one embodiment, conductive pillars **234** are formed by plating Cu in the patterned areas of the photoresist. Conductive pillars **234** have a height ranging from 2-120 μm. The photoresist is stripped away leaving behind individual conductive pillars **234**. In another embodiment, TMI conductive pillars **234** can be replaced with solder balls or stud bumps.

A plurality of semiconductor die **236** with contact pads **237** are mounted to interface layer **232** with pre-applied and stripable adhesive **238**. Semiconductor die **236** each include a substrate with an active region containing analog or digital circuits implemented as active devices, passive devices, conductive layers, and dielectric layers formed within the semiconductor die and electrically interconnected according to the electrical design of the semiconductor die. For example, the circuit may include one or more transistors, diodes, inductors, capacitors, resistors, and other circuit elements formed within

the active region of semiconductor die **236** to implement analog circuits or digital circuits, such as DSP, ASIC, memory, or other signal processing circuit.

Contact pads **237** are formed over an active surface of semiconductor die **236** using PVD, CVD, electrolytic plating, electroless plating process, or other suitable metal deposition process. Contact pads **237** can be one or more layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable electrically conductive material. Contact pads **237** electrically connected to the circuits on the active surface. Contact pads **237** can be disposed side-by-side a first distance from the edge of semiconductor die **236**. Alternatively, contact pads **237** can be offset in multiple rows such that a first row of contact pads is disposed a first distance from the edge of the die, and a second row of contact pads alternating with the first row is disposed a second distance from the edge of the die.

An encapsulant or molding compound **240**, similar to encapsulant **116** in FIG. 4e, is deposited over semiconductor die **236**, over carrier **230** and interface layer **232**, and around conductive pillars **234**. Encapsulant **240** is deposited using a paste printing, compressive molding, transfer molding, liquid encapsulant molding, vacuum lamination, or other suitable applicator. Encapsulant **240** can be polymer composite material, such as epoxy resin with filler, epoxy acrylate with filler, or polymer with proper filler. Encapsulant **240** is non-conductive and environmentally protects the semiconductor device from external elements and contaminants. Encapsulant **240** has a CTE that is adjusted to match that of the base semiconductor material, e.g., Si, with a high Tg in the range of 100° C. to 300° C. to reduce warpage. The CTE of encapsulant **240** can be adjusted using a filler such as a powder, fiber, or cloth additive. A suitable encapsulant material is generally characterized by good thermal conductivity similar to Si, low-shrinkage, high-resistivity of greater than 1.0 kohm-cm, low-dielectric constant of less than 3.5, and low-loss tangent of less than 0.02.

Encapsulant **240** undergoes grinding or plasma etching to expose a top surface of conductive pillars **234** and a backside surface of semiconductor die **236**. Alternatively, encapsulant **240** is deposited with a partially exposed molding technology such that encapsulant **240** does not cover the top surface of conductive pillars **234** and semiconductor die **236**. In either instance, conductive pillars **234** represent a TMI structure. A height of the exposed surface of conductive pillars **234** is less than a height of a backside surface of semiconductor die **236**. As a result, a height of encapsulant **240** adjacent to the backside surface of semiconductor die **236** is greater than a height of encapsulant **240** formed over carrier **230** and in a periphery of conductive pillars **234** outside a footprint of semiconductor die **236**. A portion of a top surface of encapsulant **240** includes a tapered or sloped profile that extends from a first height of encapsulant **240** formed in a periphery of conductive pillars **234** to a backside surface of semiconductor die **236** at a second height. The second height is greater than the first height. In one embodiment, the difference between the first height and the second height is in a range of 10-200 μm . The difference between the first height and the second height can be changed by removing a portion of the backside surface of semiconductor die **236** and a portion of encapsulant **240** in a periphery of the backside of semiconductor die **236** with backgrinding or other suitable process.

An insulation or passivation layer **242** is formed over conductive pillars **234**, encapsulant **240**, and semiconductor die **236** using PVD, CVD, screen printing, spin coating, spray coating, sintering or thermal oxidation. Insulation layer **242** contains one or more layers of SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, polyimide, BCB, PBO, or other material having simi-

lar insulating and structural properties. In one embodiment, insulation layer **242** is a photosensitive dielectric polymer low-cured at less than 200° C. Insulation layer **242** is conformally applied to, follows the contours of, and uniformly covers conductive pillars **234**, encapsulant **240**, and semiconductor die **236**. In one embodiment, a portion of insulation layer **242** is removed by etching or other suitable process to expose a top surface of conductive pillars **234**. The insulation layer **242** is used to planarize the wafer topography and is optional.

An electrically conductive layer **244** is formed over conductive pillars **234** and insulation layer **242** using a patterning and metal deposition process such as printing, PVD, CVD, sputtering, electrolytic plating, electroless plating, metal evaporation, metal sputtering, or other suitable metal deposition process. Conductive layer **244** is one or more layers of Al, Cu, Sn, Ni, Au, Ag, Ti, or other suitable electrically conductive material. In one embodiment, conductive layer **244** is a multi-layer RDL structure containing Ti/Cu or Ti/Al alloy. Conductive layer **244** follows the contour of insulation layer **242**, the openings in insulation layer **242** over conductive pillars **234**, and portions of conductive pillars **234** exposed by the openings in insulation layer **242**. Conductive layer **244** operates as an RDL to extend electrical connection with respect to conductive pillar **234**.

An insulation or passivation layer **246** is formed over insulation layer **242** and conductive layer **244** using PVD, CVD, screen printing, spin coating, spray coating, sintering or thermal oxidation. Insulation layer **246** contains one or more layers of SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, polyimide, BCB, PBO, or other material having similar insulating and structural properties. In one embodiment, insulation layer **246** is a photosensitive dielectric polymer low-cured at less than 200° C. Insulation layer **246** is formed over insulation layer **242** and conductive layer **244** to planarize the wafer topography and protect the conductive layer. A portion of insulation layer **246** is removed by etching or other suitable process to expose conductive layer **244** for package level interconnection. Additional insulation layers and conductive layers can be added to the device structure as needed for interconnect functionality.

In FIG. 10b, carrier **230**, interface layer **232**, and adhesive **238** are removed by chemical etching, mechanical peel-off, CMP, mechanical grinding, thermal bake, laser scanning, or wet stripping. An optional protective layer can be formed over conductive layer **244** and insulation layer **246** opposite carrier **230** either before or after the removal of the carrier and interface layer **232**.

An insulation or passivation layer **248** is formed over an active surface of semiconductor die **236**, conductive pillars **234**, and encapsulant **240** using PVD, CVD, screen printing, spin coating, spray coating, sintering or thermal oxidation. Insulation layer **248** contains one or more layers of SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, polyimide, BCB, PBO, or other material having similar insulating and structural properties. In one embodiment, insulation layer **248** is a photosensitive dielectric polymer low-cured at less than 200° C. Insulation layer **248** is formed over and protects conductive pillars **234** and semiconductor die **236**. A portion of insulation layer **248** is removed by etching or other suitable process to expose a bottom portion of conductive pillar **234** and contact pads **237**.

An electrically conductive layer **250** is formed over conductive pillars **234**, contact pads **237**, and insulation layer **248** using a patterning and metal deposition process such as printing, PVD, CVD, sputtering, electrolytic plating, electroless plating, metal evaporation, metal sputtering, or other suitable

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metal deposition process. Conductive layer **250** is one or more layers of Al, Cu, Sn, Ni, Au, Ag, Ti, or other suitable electrically conductive material. In one embodiment, conductive layer **250** is a multi-layer RDL structure containing Ti/Cu or Ti/Al alloy. Conductive layer **250** follows the contour of insulation layer **248**, the openings in insulation layer **248** over conductive pillars **234**, and portions of conductive pillars **234** exposed by the openings in insulation layer **248**. Conductive layer **250** operates as an RDL to extend electrical connection with respect to conductive pillar **234** and semiconductor die **236**.

An insulation or passivation layer **252** is formed over conductive layer **250** and insulation layer **248** using PVD, CVD, screen printing, spin coating, spray coating, sintering or thermal oxidation. Insulation layer **252** contains one or more layers of SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, polyimide, BCB, PBO, or other material having similar insulating and structural properties. In one embodiment, insulation layer **252** is a photosensitive dielectric polymer low-cured at less than 200° C. Insulation layer **252** is formed over and protects conductive layer **250**. A portion of insulation layer **252** is removed by etching or other suitable process to expose a portion of conductive layer **250**.

An electrically conductive bump material is deposited over conductive layer **250** using an evaporation, electrolytic plating, electroless plating, ball drop, or screen printing process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to conductive layer **250** using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form spherical balls or bumps **254**. In some applications, bumps **254** are reflowed a second time to improve electrical contact to conductive layer **250**. The bumps can also be compression bonded to conductive layer **250**. Bumps **254** represent one type of interconnect structure that can be formed over conductive layer **250**. The interconnect structure can also use bond wires, 3-D interconnects, conductive paste, stud bump, micro bump, or other electrical interconnect. Bumps **254** of the 3-D FO-WLCSP provide electrical connection for semiconductor die **236** to external devices through a vertical interconnect structure including conductive layer **244**, conductive layer **250**, and TMI conductive pillars **234**.

FIG. 11 shows an alternate embodiment of a 3-D FO-WLCSP similar to the 3-D FO-WLCSP from FIGS. 4a-4k, with similar elements having the same numbers. FIG. 11 differs from FIGS. 4a-4k in that encapsulant **260** remains disposed over semiconductor die **112** rather than exposing a backside surface of the semiconductor die with respect to the encapsulant as shown, e.g., in FIG. 4e.

In FIG. 11 an encapsulant or molding compound **260**, similar to encapsulant **116** in FIG. 4e, is deposited over semiconductor die **112**, over a carrier and interface layer, and around conductive pillars **110**. Encapsulant **260** is deposited using a paste printing, compressive molding, transfer molding, liquid encapsulant molding, vacuum lamination, or other suitable applicator. Encapsulant **260** can be polymer composite material, such as epoxy resin with filler, epoxy acrylate with filler, or polymer with proper filler. Encapsulant **260** is non-conductive and environmentally protects the semiconductor device from external elements and contaminants. Encapsulant **260** has a CTE that is adjusted to match that of the base semiconductor material, e.g., Si, with a high T_g in the range of 100° C. to 300° C. to reduce warpage. The CTE of encapsulant **260** can be adjusted using a filler such as a pow-

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der, fiber, or cloth additive. A suitable encapsulant material is generally characterized by good thermal conductivity similar to Si, low-shrinkage, high-resistivity of greater than 1.0 kohm-cm, low-dielectric constant of less than 3.5, and low-loss tangent of less than 0.02.

Encapsulant **260** undergoes grinding or plasma etching to expose the top surface of conductive pillars **110**. The grinding and etching does not expose a backside surface of semiconductor die **112** such that a layer of encapsulant **260** remains over an entire backside surface of, and passivates, semiconductor die **112**. Alternatively, encapsulant **260** is deposited with a partially exposed molding technology such that encapsulant **260** does not cover the top surface of conductive pillars **110**, but does cover a backside surface of semiconductor die **112**. In either instance, conductive pillars **110** represent a TMI structure with a portion of conductive pillar **110** being exposed from encapsulant **260**. A height of the exposed surface of conductive pillars **110** is less than a height of a backside surface of semiconductor die **112**. As a result, a height of encapsulant **260** over the backside surface of semiconductor die **112** is greater than a height of encapsulant **260** formed in a periphery of conductive pillars **110** outside a footprint of semiconductor die **112**. A portion of a top surface of encapsulant **260** includes a tapered or sloped profile that extends from a first height of encapsulant **260** formed in a periphery of conductive pillars **110** to over a backside surface of semiconductor die **112** at a second height. The second height is greater than the first height. In one embodiment, the difference between the first height and the second height is in a range of 10-200 μm. The difference between the first height and the second height can be changed by removing a portion of encapsulant **260** over the backside surface of semiconductor die **112**.

FIG. 12 shows an alternate embodiment of a 3-D FO-WLCSP similar to the 3-D FO-WLCSP from FIGS. 10a-10b, with similar elements having the same numbers. FIG. 12 differs from FIGS. 10a-10b in that encapsulant **262** remains disposed over semiconductor die **236** rather than exposing a backside surface of the semiconductor die with respect to encapsulant **240** shown in FIGS. 10a-10b.

In FIG. 12, an encapsulant or molding compound **262**, similar to encapsulant **240** shown in FIGS. 10a-10b, is deposited over semiconductor die **236**, over a carrier and interface layer, and around conductive pillars **234**. Encapsulant **262** is deposited using a paste printing, compressive molding, transfer molding, liquid encapsulant molding, vacuum lamination, or other suitable applicator. Encapsulant **262** can be polymer composite material, such as epoxy resin with filler, epoxy acrylate with filler, or polymer with proper filler. Encapsulant **262** is non-conductive and environmentally protects the semiconductor device from external elements and contaminants. Encapsulant **262** has a CTE that is adjusted to match that of the base semiconductor material, e.g., Si, with a high T_g in the range of 100° C. to 300° C. to reduce warpage. The CTE of encapsulant **262** can be adjusted using a filler such as a powder, fiber, or cloth additive. A suitable encapsulant material is generally characterized by good thermal conductivity similar to Si, low-shrinkage, high-resistivity of greater than 1.0 kohm-cm, low-dielectric constant of less than 3.5, and low-loss tangent of less than 0.02.

Encapsulant **262** undergoes grinding or plasma etching to expose the top surface of conductive pillars **234**. The grinding and etching does not expose a surface of semiconductor die **236** such that a layer of encapsulant **262** remains over an entire backside surface of, and passivates, semiconductor die **236**. Alternatively, encapsulant **262** is deposited with a partially exposed molding technology such that encapsulant **262**

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does not cover the top surface of conductive pillars **234**, but does cover a backside surface of semiconductor die **236**. In either instance, conductive pillars **234** represent a TMI structure with a portion of conductive pillar **234** being exposed from encapsulant **262**. A height of the exposed surface of conductive pillars **234** is less than a height of a backside surface of semiconductor die **236**. As a result, a height of encapsulant **262** over the backside surface of semiconductor die **236** is greater than a height of encapsulant **262** formed in a periphery of conductive pillars **234** outside a footprint of semiconductor die **236**. A portion of a top surface of encapsulant **262** includes a tapered or sloped profile that extends from a first height of encapsulant **262** formed in a periphery of conductive pillars **234** to over a backside surface of semiconductor die **236** at a second height. The second height is greater than the first height. In one embodiment, the difference between the first height and the second height is in a range of 10-200 μm . The difference between the first height and the second height can be changed by removing a portion of encapsulant **262** over the backside surface of semiconductor die **236** and a portion of encapsulant **262** in a periphery of the backside of semiconductor.

FIGS. **13a-13x** illustrate, in relation to FIGS. **1** and **2a-2c**, another process of forming a vertical interconnect structure for a 3-D FO-WLCSP. In FIG. **13a**, a substrate or temporary carrier **270** contains dummy or sacrificial base material such as Si, polymer, polymer composite, metal, ceramic, glass, glass epoxy, beryllium oxide, or other suitable low-cost, rigid material or bulk semiconductor material for structural support. Carrier **270** can be circular or rectangular according to the design or function of the semiconductor package.

An interface layer or double-sided carrier tape **272** is formed over carrier **270** as a temporary adhesive bonding film or etch-stop layer. As carrier tape, interface layer **272** can be either heat or light releasable material. In an alternate embodiment, interface layer **272** is an etch stop layer of SiO_2 , Si_3N_4 , SiON , organic film, or metal film with wet etching selectivity. Interface layer **272** is deposited using lamination, PVD, CVD, printing, spin coating, spray coating, sintering thermal oxidation, or other suitable process.

In FIG. **13b**, a semiconductor die **276**, similar to semiconductor die **112** from FIGS. **3a-3c** is mounted over carrier **270** with an active surface of the semiconductor die oriented toward substrate **270** and interface layer **272**. Semiconductor die **276** includes contact pads **277** formed over the active surface of semiconductor die **276**. Contact pads **277** are made with a conductive material such as Al, Cu, Sn, Ni, Au, or Ag, and are electrically connected to circuit elements formed within semiconductor die **276**. Contact pads **277** are formed by PVD, CVD, electrolytic plating, electroless plating, or other suitable process. An insulation or passivation layer **278** is formed over the active surface of semiconductor die **276**. Insulation layer **278** is conformally applied over semiconductor die **276** using PVD, CVD, screen printing, spin coating, spray coating, sintering or thermal oxidation. Insulation layer **278** contains one or more layers of SiO_2 , Si_3N_4 , SiON , Ta_2O_5 , Al_2O_3 , or other material having similar insulating and structural properties. Insulation layer **278** covers and protects one or more transistors, diodes, or other circuit elements formed within the active surface of semiconductor die **276** including IPDs, such as inductors, capacitors, and resistors. In one embodiment, insulation layer **278** is an optically transparent or translucent dielectric material for passing light to active surface of semiconductor die **276**. A portion of insulation layer **278** is removed from over a portion of contact

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pads **277**. The openings in insulation layer **278** over contact pads **277** facilitate future electrical interconnect with semiconductor die **276**.

Leading with the active surface of semiconductor die **276**, the semiconductor die is mounted over carrier **270** and interface layer **272**. Insulation layer **278** contacts interface layer **272** including a portion of insulation layer **278** in a periphery of, and around, the openings in insulation layer **278** to prevent subsequently formed encapsulant from contacting contact pads **277**.

In FIG. **13c**, printed dots or nodules **280** are formed on interface layer **272** and in a periphery of semiconductor die **276** with screen printing, jetting, or other suitable process. Printed dots **280** are a solvent removable material such as a photoresist layer, dry film, or paste that is removed by an etching process after exposure to a 150°C . heat treatment for one hour. Alternatively, printed dots **280** are a water removable material after exposure to a 150°C . heat treatment for one hour. Printed dots **280** are formed before semiconductor **276** is mounted over carrier **270** and interface layer **272**. Alternatively, printed dots **280** are formed after semiconductor **276** is mounted over carrier **270** and interface layer **272**. Printed dots **280** include a round or circular shape, a ring shape, a dam configuration, a straight line shape, or any other suitable shape according to the configuration and design of the application. Printed dots **280** provide a cavity or void in a later formed encapsulant as discussed in further detail below.

FIGS. **13d-13e**, similar to FIGS. **13b-13c**, show an alternate embodiment including a temporary planarization and protection layer **282** formed over insulation layer **278**. While FIGS. **13d-13w** show a process flow for a semiconductor device including the use of temporary planarization layer **282**, the temporary planarization layer is optional, and steps similar to those shown in FIGS. **13d-13w** are used to form a 3-D FO-WLCSP device without the use of temporary planarization layer **282**. Accordingly, any of the embodiments presented in the figures can be made with or without temporary planarization layer **282**. Temporary planarization layer **282** is conformally applied over, and follows the contours of, insulation layer **278** with spin coating, vacuum or pressure lamination with or without heat, screen printing, slit coating, spray coating, or other suitable process. Temporary planarization layer **282** is a solvent removable material such as a photoresist layer or dry film that is removed by an etching process after exposure to a 150°C . heat treatment for one hour. Alternatively, temporary planarization layer **282** is a water removable material after exposure to a 150°C . heat treatment for one hour. A first surface of temporary planarization layer **282** follows a contour of a top surface of insulation layer **278**, follows a contour of a sidewall of the openings in insulation layer **278**, and is formed over contact pads **277** of semiconductor die **276**. A second surface of temporary planarization layer **282** opposite the first surface is substantially planar and facilitates the subsequent mounting of semiconductor die **276** to interface layer **272** over carrier **270**. Temporary planarization layer **282** provides increased offset between the active surface of semiconductor die **276** and a top surface of interface layer **272**.

In FIG. **13e**, printed dots or nodules **280** are formed on interface layer **272** and in a periphery of semiconductor die **276** as previously described in FIG. **13c**. FIG. **13e** further shows semiconductor die **276** is mounted over carrier **270** and interface layer **272** with the active surface of the semiconductor die oriented towards the carrier and the interface layer. Temporary planarization layer **282** contacts interface layer **272** providing increased offset between the active surface of semiconductor die **276** and a top surface of interface layer

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272, preventing subsequently formed encapsulant from being formed over contact pads 277.

In FIG. 13f, an optional backside alignment unit 284 is formed over the surface of carrier 270 and interface layer 272. Backside alignment unit 284 contains an alignment key for subsequent laser drilling and marking, or for next level surface mount technology (SMT) alignment. Backside alignment unit 284 provides alignment when a portion of the backside alignment unit opposite interface layer 272 is exposed. A plurality of backside alignment units 284 are located over portions of carrier 270 that facilitate alignment of a plurality of semiconductor die 276 at a reconstituted wafer level. Backside alignment units 284 are, for example, located at four symmetrical positions alternately spaced near an edge of carrier 270 for global or wafer level alignment. The alignment of carrier 270 and semiconductor die 276 facilitates subsequent process steps performed at the reconstituted wafer level including laser drilling, marking, and lithography exposure processes.

In FIG. 13g, an encapsulant or molding compound 286 is deposited over and around semiconductor die 276, printed dots 280, alignment unit 284, and over interface layer 272 using a paste printing, compressive molding, transfer molding, liquid encapsulant molding, vacuum lamination, or other suitable applicator. Encapsulant 286 can be polymer composite material, such as epoxy resin with filler, epoxy acrylate with filler, or polymer with proper filler. Encapsulant 286 is non-conductive, provides physical support, and environmentally protects the semiconductor device from external elements and contaminants. In one embodiment, encapsulant 286 has a CTE that is adjusted to match that of the base semiconductor material, e.g., Si, with a high T_g in the range of 100° C. to 300° C. to reduce warpage. The CTE of encapsulant 286 can be adjusted using a filler such as a powder, fiber, or cloth additive. A suitable encapsulant material is generally characterized by good thermal conductivity similar to Si, low-shrinkage, high-resistivity of greater than 1.0 kohm-cm, low-dielectric constant of less than 3.5, and low-loss tangent of less than 0.02.

Before mounting and encapsulating semiconductor die 276 over carrier 270, semiconductor die 276 undergo a back grinding process to thin semiconductor die 276 to a desired thickness. Alternatively, semiconductor die 276 undergo back grinding at the reconstituted wafer level after being mounted to carrier 270 and encapsulated with encapsulant 286.

In FIG. 13h, carrier 270 and interface layer 272 are removed by chemical etching, mechanical peeling, CMP, mechanical grinding, thermal bake, ultra-violet (UV) light, laser scanning, or wet stripping to expose a bottom surface of encapsulant 286, and a bottom surface of temporary planarization layer 282 or insulation layer 278. FIG. 13h further shows printed dots 280 are removed to form openings or voids 288 in encapsulant 286 located in a periphery of semiconductor die 276, insulation layer 278, and temporary planarization layer 282. Alternatively, in the absence of forming printed dots 280, after the removal of carrier 270, a portion of encapsulant 286 is removed to form openings 288. The portion of encapsulant 286 removed to form openings 288 is removed by laser drilling or other suitable method. Openings 288 are shallow vias or cavities formed in a bottom surface of encapsulant 286 in a periphery of semiconductor die 276, insulation layer 278, and temporary planarization layer 282. Openings 288 extend from the bottom surface of encapsulant 286 partially but not completely through encapsulant 286. Openings 288 are configured to receive subsequently formed insulation

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and conductive layers that form a portion of an interconnect layer that provides electrical connection with respect to semiconductor die 276.

FIG. 13i shows openings 288 with sidewalls 290 and bottom portions 292. Sidewalls 290 are tapered rather than vertical as shown in FIG. 13h. Bottom portions 292 are planar and have an area that is less than an area of a footprint of a portion of opening 288 that is coplanar with the bottom surface of encapsulant 286. Tapered sidewalls 290 are formed by laser drilling or other suitable method at the time when openings 288 are formed. Alternatively, tapered sidewalls 290 are formed after the initial formation of openings 288, e.g. after the formation of openings 288 with the removal of printed dots 280. As a further alternative, openings 288 are formed with tapered sidewalls upon removal of printed dots 280. FIG. 13i further shows the formation of openings 294 around a periphery of semiconductor die 276. Openings 294 are formed by the removal of encapsulant 286 by laser drilling or other suitable process and provide a smooth contour at the interface between semiconductor die 276 and encapsulant 286.

In FIG. 13j, temporary planarization layer 282 is removed. Temporary planarization layer 282 is removed with a wet cleaning process including solvent, an aqueous clean with carbon dioxide (CO₂) dosing, or other suitable process. The removal of temporary planarization layer 282 exposes insulation layer 278 and portions of contact pads 277 not covered by insulation layer 278. The removal of temporary planarization layer 282, which provided increased offset between the active surface of semiconductor die 276 and the top surface of interface layer 272, further provides opening or cavity 296. Opening 296 is formed over the active surface of semiconductor die 276 and extends from a level of a bottom or backside surface of encapsulant 286 to insulation layer 278 and contact pads 277 of semiconductor die 276. A surface of opening 296 follows a contour of a sidewall of encapsulant 286, extends along insulation layer 278, along a sidewall of the openings in insulation layer 278 over contact pads 277, and along a surface of contact pads 277.

In an alternate embodiment, temporary planarization layer 282 is not entirely removed but remains over the active surface of semiconductor die 276 and insulation layer 278 as an additional insulation or dielectric layer. In the embodiment where temporary planarization layer 282 is not entirely removed, the temporary planarization layer contains one or more layers of SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, hafnium oxide (HfO₂), photosensitive polyimide, non-photosensitive polyimide, BCB, PBO, dielectric film material, or other material having similar insulating and structural properties with a curing temperature of less than or equal to 380° C. A portion of temporary planarization layer 282 is removed from over contact pads 277 by laser drilling, UV exposure, or other suitable process to form an opening or via which exposes a portion of contact pads 277. The portion of temporary planarization layer 282 removed from over contact pads 277 is removed after the curing of the temporary planarization layer, or alternatively, is removed before semiconductor die 276 is singulated and mounted over carrier 270. Furthermore, a portion of insulation layer 278 can also be removed in a same process step as the removal of the portion of temporary planarization layer 282 in order to expose the portion of contact pads 277.

In FIG. 13k, a first portion of a FO-WLCSP interconnect or RDL is formed by the deposition and patterning of insulation or passivation layer 298 and the deposition and patterning of conductive layer 302. Insulation layer 298 is conformally applied to, and has a first surface that follows the contours of,

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encapsulant **286**, openings **288** including sidewalls **290** and bottom surfaces **292**, and opening **296**. Insulation layer **298** has a second planar surface opposite the first surface. Insulation layer **298** contains one or more layers of photosensitive low curing temperature dielectric resist, photosensitive composite resist, liquid crystal polymer (LCP), laminate compound film, insulation paste with filler, solder mask resist film, liquid molding compound, granular molding compound, polyimide, BCB, PBO, SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, polytetrafluoroethylene pre-impregnated (prepreg), or other material having similar insulating and structural properties. In one embodiment, insulation layer **298** is a composite material including a prepreg material and a resin, such as epoxy-based resin, the resin enhanced with woven fiber, cloth, glass, or woven glass. Insulation layer **298** is deposited using printing, spin coating, spray coating, vacuum or pressure lamination with or without heat, or other suitable process. Insulation layer **298** is subsequently patterned with UV or laser exposure followed by developing with a chemical process or other suitable process. Insulation layer **298** is cured with a thermal process, for example, by oven curing, or by UV exposure. A portion of insulation layer **298** is removed by developing with a chemical process, laser ablation, etching, or other suitable process to expose bottom surfaces **292** of openings **288** and contact pads **277** of semiconductor die **276** according to the configuration and design of semiconductor die **276**.

An electrically conductive layer **302** is patterned and deposited over encapsulant **286**, semiconductor die **276**, and insulation layer **298**. Conductive layer **302** can be one or more layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable electrically conductive material. The deposition of conductive layer **302** uses PVD, CVD, electrolytic plating, electroless plating, or other suitable process. In one embodiment, conductive layer **302** includes a seed layer of Ti/Cu, TiW/Cu, or a coupling agent/Cu. The seed layer is deposited by sputtering, electroless plating, or by depositing laminated Cu foil combined with electroless plating. In one embodiment, conductive layer **302** has a thickness of at least 8 μm within the openings in insulation layer **298**. The openings in insulation layer **298** extend completely through the insulation layer over openings **288** and over contact pads **277**. Conductive layer **302** operates as a RDL to extend electrical connection from semiconductor die **276** to points external to semiconductor die **276**. A portion of conductive layer **302** formed within openings **288** forms lands on the bottom surfaces **292** of openings **288** that serve as a stop layer for subsequent drilling or removal of a portion of encapsulant **286** from the top side of encapsulant **286**. In one embodiment, the portion of conductive layer **302** formed within openings **288** has a width that is greater than a width of the portion of conductive layer **302** formed over contact pads **277**.

In FIG. **13l**, insulation or passivation layer **306** is conformally applied to, and follows the contours of, insulation layer **298** and conductive layer **302**. Insulation layer **306** contains one or more layers of photosensitive low curing temperature dielectric resist, photosensitive composite resist, LCP, laminate compound film, insulation paste with filler, solder mask resist film, liquid molding compound, granular molding compound, polyimide, BCB, PBO, SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, prepreg, or other material having similar insulating and structural properties. In one embodiment, insulation layer **306** is a composite material including a prepreg material and a resin, such as epoxy-based resin, the resin enhanced with woven fiber, cloth, glass, or woven glass. Insulation layer **306** is deposited using printing, spin coating, spray coating, vacuum or pressure lamination with or without heat, or other

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suitable process. Insulation layer **306** is subsequently patterned with UV or laser exposure followed by developing with a chemical process or other suitable process. Insulation layer **306** is cured with a thermal process, for example, by oven curing, or by UV exposure. A portion of insulation layer **306** is removed by developing with a chemical process, laser ablation, etching, or other suitable process to expose portions of conductive layer **302**.

An electrically conductive layer **310** is patterned and deposited over conductive layer **302**, insulation layer **306**, semiconductor die **276**, and encapsulant **286**. Conductive layer **310** can be one or more layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable electrically conductive material. The deposition of conductive layer **310** uses PVD, CVD, electrolytic plating, electroless plating, or other suitable process. In one embodiment, conductive layer **310** includes a seed layer of Ti/Cu, TiW/Cu, or a coupling agent/Cu. The seed layer is deposited by sputtering, electroless plating, or by depositing laminated Cu foil combined with electroless plating. In one embodiment, conductive layer **310** has a thickness of at least 8 μm within openings in insulation layer **306**. The openings in insulation layer **306** extend completely through the insulation layer over conductive layer **302**. Conductive layer **310** operates as an RDL to extend electrical connection from semiconductor die **276**, through conductive layer **302**, to points external to semiconductor die **276**.

In FIG. **13m**, insulation or passivation layer **314** is conformally applied to, and follows the contours of, insulation layer **306** and conductive layer **310**. Insulation layer **314** contains one or more layers of photosensitive low curing temperature dielectric resist, photosensitive composite resist, LCP, laminate compound film, insulation paste with filler, solder mask resist film, liquid molding compound, granular molding compound, polyimide, BCB, PBO, SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, prepreg, or other material having similar insulating and structural properties. In one embodiment, insulation layer **314** is a composite material including a prepreg material and a resin, such as epoxy-based resin, the resin enhanced with woven fiber, cloth, glass, or woven glass. Insulation layer **314** is deposited using printing, spin coating, spray coating, vacuum or pressure lamination with or without heat, or other suitable process. Insulation layer **314** is subsequently patterned with UV or laser exposure followed by developing with a chemical process or other suitable process. Insulation layer **314** is cured with a thermal process, for example, by oven curing, or by UV exposure. A portion of insulation layer **314** is removed by developing with a chemical process, laser ablation, etching, or other suitable process to expose portions of conductive layer **310**.

An electrically conductive layer **318** is patterned and deposited over conductive layer **310**, insulation layer **314**, semiconductor die **276**, and encapsulant **286**. Conductive layer **318** can be one or more layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable electrically conductive material. The deposition of conductive layer **318** uses PVD, CVD, electrolytic plating, electroless plating, or other suitable process. In one embodiment, conductive layer **318** includes a seed layer of Ti/Cu, TiW/Cu, or a coupling agent/Cu. The seed layer is deposited by sputtering, electroless plating, or by depositing laminated Cu foil combined with electroless plating. In one embodiment, conductive layer **318** has a thickness of at least 8 μm within the openings in insulation layer **314** that extend completely through the insulation layer over conductive layer **310**. Conductive layer **318** operates as an RDL to extend electrical connection from semiconductor die **276**, through conductive layers **302** and **310**, to points external to semiconductor die **276** according to the configuration and design of

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semiconductor die 276. Taken together, insulation layers 298, 306, and 314 as well as conductive layers 302, 310, and 318, form interconnect structure 320. The number of insulation and conductive layers included within interconnect 320 depends on, and varies with, the complexity of circuit routing design. Accordingly, interconnect 320 can include any number of insulation and conductive layers to facilitate electrical interconnect with respect to semiconductor die 276. Furthermore, elements that would otherwise be included in a backside interconnect structure or RDL can be integrated as part of interconnect 320 to simplify manufacturing and reduce fabrication costs with respect to a package including both front side and backside interconnects or RDLs.

In FIG. 13n, insulation or passivation layer 322 is conformally applied to, and follows the contours of, insulation layer 314 and conductive layer 318. Insulation layer 322 contains one or more layers of photosensitive low temperature curing dielectric resist, photosensitive composite resist, LCP, laminate compound film, insulation paste with filler, solder mask resist film, liquid molding compound, granular molding compound, polyimide, BCB, PBO, SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, prepreg, or other material having similar insulating and structural properties. In one embodiment, insulation layer 322 is a composite material including a prepreg material and a resin, such as epoxy-based resin, the resin enhanced with woven fiber, cloth, glass, or woven glass. Insulation layer 322 is deposited using printing, spin coating, spray coating, vacuum or pressure lamination with or without heat, or other suitable process. Insulation layer 322 is subsequently patterned with UV or laser exposure followed by developing with a chemical process or other suitable process. Insulation layer 322 is cured with a thermal process, for example, by oven curing, or by UV exposure. A portion of insulation layer 322 is removed by developing with a chemical process, laser ablation, etching, or other suitable process to expose portions of conductive layer 318.

An electrically conductive bump material is deposited over conductive layer 318 and insulation layer 322 using an evaporation, electrolytic plating, electroless plating, ball drop, or screen printing process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to conductive layer 318 using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form spherical balls or bumps 326. In some applications, bumps 326 are reflowed a second time to improve electrical contact to conductive layer 318. In one embodiment, bumps 326 are formed over a UBM having a wetting layer, barrier layer, and adhesive layer. The bumps can also be compression bonded to conductive layer 318. Bumps 326 represent one type of interconnect structure that can be formed over conductive layer 318. The interconnect structure can also use bond wires, conductive paste, stud bump, micro bump, or other electrical interconnect.

FIGS. 13o-13q, similar to FIG. 13n, show alternate interconnect structures that can be electrically connected to interconnect 320 for extending electrical connection from semiconductor die 276 to points external to semiconductor die 276. In FIG. 13o, instead of bumps 326, bumps 328 are formed over conductive layer 318. Bumps 328 are Ni/Au, Ni/Pt/Au, or Ni/Pd/Au and are formed as input/output (I/O) pads for extending electrical connection from semiconductor die 276 to points external to semiconductor die 276.

In FIG. 13p, bumps 332 are formed over conductive layer 318. Bumps 332 include plated copper columns and are

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formed as I/O pads for extending electrical connection from semiconductor die 276 to points external to semiconductor die 276.

In FIG. 13q, bumps 336 are formed over conductive layer 310. Bumps 336 include plated copper and are formed as I/O pads for extending electrical connection from semiconductor die 276 to points external to semiconductor die 276. FIG. 13q differs from FIGS. 13n-13p in that a final insulation layer 338, similar to insulation layer 322, covers both conductive layer 310 and bumps 336. Thus, final insulation layer 338 is formed after the formation of bumps 336. In other words, bumps 336 are formed over conductive layer 310 before the formation of insulation layer 338.

In FIG. 13r, back grinding tape 342 is applied over semiconductor die 276, encapsulant 286, interconnect 320, and bumps 326, 328, 332, or 336. Back grinding tape 342 contacts the final or bottom most layer of interconnect 320, such as insulation layer 322, and further contacts final I/O pads such as bumps 326. Back grinding tape 342 follows the contours of a surface of bumps 326 and extends around and between bumps 326. Back grinding tape 342 includes tapes with thermal resistance up to 270° C. Back grinding tape 342 also includes tapes with a thermal releasing function. Examples of back grinding tapes 342 include UV tape HT 440 and non-UV tape MY-595. Back grinding tape 342 provides structural support for subsequent back grinding and removal of a portion of encapsulant 286 from a backside or top surface of encapsulant 286 opposite interconnect 320.

In FIG. 13r, top surface of encapsulant 286 opposite interconnect 320 undergoes a grinding operation with grinder 344 to planarize the surface and reduce a thickness of the encapsulant. The grinding operation reduces a thickness of the reconstituted wafer to a thickness in the range of 50 to 600 um. A chemical etch can also be used to remove and planarize encapsulant 286. After the grinding operation is completed a layer of encapsulant 286 covers a backside surface of semiconductor wafer 276. Alternatively, a backside surface of semiconductor die 276 is exposed from encapsulant 286 after the grinding operation, and a thickness of semiconductor die 276 is also reduced by the grinding operation. In another embodiment, back grinding tape 342 is merely supporting tape with either a UV or thermal releasing function such that the tape, when removed, is removed without a back grinding process.

FIG. 13s shows an embodiment in which a backside surface of semiconductor die 276 is exposed from encapsulant 286 after the grinding operation. An encapsulant or molding compound 346 is deposited over and contacts a backside surface of semiconductor die 276 and encapsulant 286 using a paste printing, compressive molding, transfer molding, liquid encapsulant molding, vacuum or pressure lamination with or without heat, or other suitable applicator. Encapsulant 346 can be polymer composite material, such as epoxy resin with filler, epoxy acrylate with filler, or polymer with proper filler. Encapsulant 346 is non-conductive, provides physical support, and environmentally protects the semiconductor device from external elements and contaminants when a need exists to protect the backside of semiconductor die 276.

FIG. 13t, continuing from FIG. 13r, shows a portion of encapsulant 286 is removed from a periphery of semiconductor die 276 and from over conductive layer 302 to form openings 350. Openings 350 include a vertical or sloped sidewall and extend from a back surface of encapsulant 286 completely through the encapsulant to bottom surface 292 of opening 288. Openings 350 are formed by drilling, laser ablation, high energy water jetting, etching, or other suitable process to expose portions of conductive layer 302. In one

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embodiment, openings 350 serve as round through encapsulant blind vias (TEBVs) that extend to, and contact, conductive layer 302. Alternatively, openings 350 include cross-sectional profiles of any shape. Openings 350 are formed and subsequently cleaned while back grinding or supporting tape 342 is attached over interconnect 320 and bumps 326. By forming openings 350 as TEBVs through encapsulant 286 in a periphery of semiconductor die 276, a portion of conductive layer 302 is exposed from a backside of encapsulant 286. Openings 350 are configured to provide subsequent 3-D electrical interconnect for semiconductor die 276 without the use of TSVs or THVs.

FIG. 13u, similar to FIG. 13t shows a portion of encapsulant 286 is removed from a periphery of semiconductor die 276 and over conductive layer 302 to form openings 352. Openings 352 include sidewalls with a first portion that is sloped, and second portion that is vertical. Openings 352 extend from a back surface of encapsulant 286 completely through the encapsulant to bottom surface 292 of opening 288. Openings 352 are formed by drilling, laser ablation, high energy water jetting, etching, or other suitable process to expose portions of conductive layer 302. Openings 352 serve as TEBVs that extend to and contact conductive layer 302. Openings 352 are formed and subsequently cleaned while back grinding or supporting tape 342 is attached over interconnect 320 and bumps 326. By forming openings 352 as TEBVs through encapsulant 286 in a periphery of semiconductor die 276, a portion of conductive layer 302 is exposed from a backside of encapsulant 286. Openings 352 are configured to provide subsequent 3-D electrical interconnect for semiconductor die 276 without the use of TSVs or THVs.

In FIG. 13v, an electrically conductive bump material is deposited in opening 350 and over conductive layer 302 using an evaporation, electrolytic plating, electroless plating, ball drop, screen printing, jetting, or other suitable process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to conductive layer 302 using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form spherical balls or bumps 356. In some applications, bumps 356 are reflowed a second time to improve electrical contact to conductive layer 302. In one embodiment, bumps 356 are formed over a UBM having a wetting layer, barrier layer, and adhesive layer. The bumps can also be compression bonded to conductive layer 302. Bumps 356 represent one type of interconnect structure that can be formed over conductive layer 302. The interconnect structure can also use bond wires, Cu, Ag, or other conductive paste, stud bump, micro bump, solder balls with a Cu core, Cu balls or columns with dipped solder paste or solder coating, or other electrical interconnect. Bumps 356 form a 3D interconnection for next level interconnection. In one embodiment, bumps 356 are formed by SMT with paste printing deposited into openings 350 at the reconstituted wafer level. Accordingly, a 3D interconnection is formed through bumps 356, conductive layer 302, interconnect 320, bumps 326, and semiconductor die 276, thereby forming through vertical electrical interconnection for 3-D FO-WLCSP without a backside interconnect or RDL over a footprint of semiconductor die 276.

In FIG. 13w, back grinding tape 342 is removed after completing the grinding of encapsulant 286, after the formation and cleaning of openings 350, and after the formation of bumps 356. Alternatively, back grinding tape 342 is removed after completing the grinding of encapsulant 286 and after the

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formation and cleaning of openings 350 but before the formation of bumps 356. Furthermore, the reconstituted wafer is singulated with saw blade or laser cutting device 360 into individual 3-D FO-WLCSPs 362. Singulation can occur before or after removal of back grinding tape 342.

FIG. 13x shows a 3-D FO-WLCSP 366, similar to 3-D FO-WLCSP 362 from FIG. 13w. 3-D FO-WLCSP 366 differs from FO-WLCSP 362 in that 3-D FO-WLCSP 366 was formed without the use of temporary planarization layer 282 as shown in FIGS. 13b and 13c. Accordingly, the offset of semiconductor die 276 with respect to the bottom surface of encapsulant 286, and the subsequent presence of opening 296 resulting from the removal of temporary planarization layer 282, is not present in 3-D FO-WLCSP 366. However, like in FIG. 13w, the reconstituted wafer is singulated with saw blade or laser cutting device 368 into individual 3-D FO-WLCSPs 366. Singulation can occur before or after removal of the back grinding tape.

3-D FO-WLCSPs 362 and 366 provide 3-D electrical interconnection with an interconnect I/O array through vertical interconnects formed outside a footprint of a semiconductor die without the use of a backside RDL extending within a footprint of the semiconductor die. Optional backside alignment units with alignment keys are embedded in the encapsulant to facilitate next level SMT alignment and package-on-package (POP) configurations. Laser drilling or other suitable method is used to form an opening in a front side of the encapsulant in a periphery of the active surface of the semiconductor die. An interconnect structure is formed over the active surface of the semiconductor die and extends into the openings in the front side of the encapsulant. The interconnect structure includes insulation and conductive layers that form a FO-WLCSP RDL. Elements that would otherwise be included in a backside interconnect structure or RDL can be integrated as part of a single interconnect structure formed over the active surface of the semiconductor die. Alternatively, backside RDL elements can be included in other later mounted components of another semiconductor device as part of a POP configuration. Bumps or other I/O interconnects are formed over the interconnect structure. Backgrinding tape is applied over the bumps, and a portion of the encapsulant and a portion of the backside of the semiconductor die are removed in a backgrinding process. Laser drilling or other suitable process removes a portion of encapsulant in a periphery of the semiconductor die to facilitate the subsequent formation of vertical interconnects such as round TEBVs that extend from a back surface of the encapsulant to the interconnect structure. The back grinding tape is removed. A bump or other suitable conductive material is formed in the TEBV to form 3D vertical interconnects for next level interconnection and POP configurations. The reconstituted wafer is singulated.

FIGS. 14a-14d, continuing from FIG. 13t, show another embodiment of forming an electrical connection with conductive layer 302 through openings 350. In FIG. 14a conductive bump material 370 is deposited in openings 350 at the reconstituted wafer level by printing, jetting, or other suitable process. Conductive bump material 370 is Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, indium (In), solder, and combinations thereof, with an optional flux solution. For example, conductive bump material 370 can be eutectic Sn/Pb, high-lead solder, or lead-free solder. Conductive bump material 370 contacts conductive layer 302 and fills a portion of openings 350 that is less than an entirety of the openings to facilitate subsequent electrical interconnect.

In FIG. 14b, a bumped semiconductor device or package 374 with bumps 376 is mounted over 3-D FO-WLCSP 378 at

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the reconstituted wafer level. Semiconductor device 374 includes interconnect elements that would otherwise be included in a backside interconnect structure or RDL formed over the backside of semiconductor 276 that are not included as part of interconnect 320. Bumps 376 are Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, In, solder, and combinations thereof, with an optional flux solution. For example, bumps 376 can be eutectic Sn/Pb, high-lead solder, or lead-free solder. Semiconductor device 374 is mounted using pick and place or other suitable operation. Semiconductor device 374 is mounted with bumps 376 oriented toward 3-D FO-WLCSP 378 such that bumps 376 extend into openings 350 and contact conductive bump material 370 within openings 350. The contact between bumps 376 and conductive bump material 370 results in an offset 379 between encapsulant 286 and a surface of semiconductor device 374. A footprint of semiconductor device 374 has an area that is larger than an area of a footprint of semiconductor die 276. Thus, the footprint of semiconductor die 276 is located within the footprint of semiconductor device 374 after the semiconductor device has been mounted to 3-D FO-WLCSP 378.

In FIG. 14c, the reconstituted wafer including semiconductor device 374 and 3-D FO-WLCSP 378 are heated to reflow bump material 370 and bumps 376. In one embodiment, bump material 370 and bumps 376 are reflowed by heating the materials above their melting points to form spherical balls or bumps 380. In some applications, bumps 380 are reflowed a second time to improve electrical contact to conductive layer 302. The bumps can also be compression bonded to conductive layer 302. Bumps 380 represent one type of interconnect structure that can be formed over conductive layer 302. The interconnect structure can also use bond wires, conductive paste, stud bump, micro bump, or other electrical interconnect.

In FIG. 14d, the reconstituted wafer including semiconductor device 374 is singulated with saw blade or laser cutting device 384 into individual 3-D FO-PoPs 386. FO-PoPs 386 are singulated before back grinding tape 342 is removed. Alternatively, back grinding tape 342 is removed after completing the grinding of encapsulant 286 and after the formation and cleaning of openings 350 but before singulation. When back grinding tape 342 is removed before singulation of FO-PoPs 386, an optional dicing tape 387 is applied over bumps 326 and contacts insulation layer 322 or the final or bottom most layer of interconnect 320, follows the contours of a surface of bumps 326, and extends around and between bumps 326.

FIGS. 15a-15d, continuing from FIG. 13t, show an alternative method for forming an electrical connection with conductive layer 302 through openings 350. After a portion of encapsulant 286 is removed from over conductive layer 302 to form openings 350, back grinding tape 342 is removed.

In FIG. 15b, the reconstituted wafer 388 including semiconductor die 276 is aligned and placed on a reusable carrier 390. Carrier 390 is made of a carrier base material, such as metal, that has thermal conductivity and stiffness properties suitable for minimizing warpage of the carrier in subsequent solder reflow cycles. Carrier 390 includes a plurality of half-ball shaped cavities 392. Cavities 392 are configured to receive bumps 326. Cavities 392 have a height that is less than a height of bumps 326. In one embodiment, cavities 392 have a height that is at least 5 μm less than a height of bumps 326. Alternatively, cavities 392 have a height that is in a range of 5-100 μm greater than a height of bumps 326. The difference in heights between bumps 326 and cavities 392 produces a gap or offset 394 between insulation layer 322 and a top surface of carrier 390. Cavities 392 also have a width that is

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greater than a width of bumps 326. In one embodiment, cavities 392 have a width that is at least 10 μm greater than a width of bumps 326. The difference in widths between bumps 326 and cavities 392 produces a gap or offset between bumps 326 and a contour or surface of cavity 392.

The offset or area between cavities 392 and bumps 326 includes a non-wettable material 396. Non-wettable material 396 is deposited on, and coats, a supporting surface of carrier 390 including a surface of cavities 392. Non-wettable material 396 includes high temperature coatings such as high temperature Teflo, Ti, TiN, or other thin film materials that are inert with respect to bumps 326. Non-wettable material 396 is configured to contact bumps 326 at high temperatures without reacting or sticking to bumps 326 or insulation layer 322. For example, non-wettable material 396 is configured to not react or stick to bumps 326 or insulation layer 322 at temperatures greater than or equal to 280° C.

In one embodiment, carrier 390 includes a vacuum with a vacuum loop or vacuum hole 397 that is configured to maintain reconstituted wafer 388 in contact with carrier 390 and non-wettable material 396.

FIG. 15c, similar to FIG. 15b, shows reconstituted wafer 388 aligned and placed on reusable carrier 390. FIG. 15c differs from FIG. 15b in that offset 394 between insulation layer 322 and a top surface of carrier 390 from FIG. 15b is replaced with offset 398. Offset 398 extends between a surface of bumps 326 and a bottom surface of cavity 392, and in one embodiment includes a distance in a range of 5-100 μm .

In FIG. 15d, with reconstituted wafer 388 mounted to reusable carrier 390, bumps 400 are deposited or formed within openings 350. An electrically conductive bump material is deposited within openings 350 and over conductive layer 302 using an evaporation, electrolytic plating, electroless plating, ball drop, or screen printing process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to conductive layer 302 using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form spherical balls or bumps 400. In some applications, bumps 400 are reflowed a second time to improve electrical contact with conductive layer 302. The bumps can also be compression bonded to conductive layer 302. Bumps 400 represent one type of interconnect structure that can be formed over conductive layer 302. The interconnect structure can also use bond wires, conductive paste, stud bump, micro bump, or other electrical interconnect.

After the formation of bumps 400, reconstituted wafer 388 is singulated with saw blade or laser cutting device 404 into individual 3-D FO-WLCSPs 406.

FIGS. 16a-16d show an alternative method for forming an electrical connection with conductive layer 302 through openings 412. FIG. 16a shows back grinding tape 410, similar to back grinding tape 342 of FIG. 13r, applied over insulation layer 322 before the formation of conductive bumps similar to bumps or I/O connects 326, 328, 332, and 336 from FIGS. 13n-13q. Back grinding tape 410 includes tapes with thermal resistance up to 270° C. and tapes with a thermal releasing function. Examples of back grinding tapes 410 include UV tape HT 440 and non-UV tape MY-595. Back grinding tape 410 provides structural support for optional back grinding of encapsulant 286 at a backside or top surface of encapsulant 286 as previously described in FIG. 13r.

After applying back grinding tape 410, a portion of encapsulant 286 is removed from over conductive layer 302 to form

openings 412. Openings 412 include a vertical or sloped sidewall and extend from a back surface of encapsulant 286 completely through the encapsulant to bottom surface 292 of opening 288. Openings 412 are formed by drilling, laser ablation, high energy water jetting, etching, or other suitable process to expose portions of conductive layer 302. In one embodiment, openings 412 serve as round TEBVs that extend to, and contact, conductive layer 302. Alternatively, openings 412 include cross-sectional profiles of any shape. Openings 412 are formed and subsequently cleaned while back grinding or supporting tape 410 is attached. By forming openings 412 as TEBVs through encapsulant 286 in a periphery of semiconductor die 276, a portion of conductive layer 302 is exposed from a backside of encapsulant 286.

In FIG. 16b, back grinding tape 410 is removed after the optional grinding of encapsulant 286, and after the formation and cleaning of openings 412.

In FIG. 16c, temporary supporting layer 416 is formed over reconstituted wafer 414. Temporary supporting layer 416 contacts insulation layer 322 and includes high temperature tape and thermal releasable tape. Temporary supporting layer 416 supports reconstituted wafer 414 during the formation and placement of bumps 418 and is removed after the formation of bumps 418.

Bumps 418 are formed by depositing an electrically conductive bump material over conductive layer 302 and within openings 412 using an evaporation, electrolytic plating, electroless plating, ball drop, screen printing compression bonding, or other suitable process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to conductive layer 302 using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form spherical balls or bumps 418. In some applications, bumps 418 are reflowed a second time to improve electrical contact to conductive layer 302. Bumps 418 represent one type of interconnect structure that can be formed over conductive layer 302. The interconnect structure can also use bond wires, conductive paste, stud bump, micro bump, or other electrical interconnect. Bumps 418 are formed with a height that is less than a height of opening 412 such that bumps 418 are recessed below a backside or top surface of encapsulant 286. In one embodiment bumps 418 have a height at least 1 μ m less than a height of openings 412.

In another embodiment, temporary supporting layer 416 is optional and is not applied after the removal of back grinding tape 410. Without temporary supporting layer 416 to provide structural support to reconstituted wafer 414 bumps 418 are formed as described above. When bumps 418 are formed by a ball drop process a chuck of the ball drop machine is used to provide temporary support during the placement of bumps 418. The chuck of the ball drop machine is coated with compliant protecting material such as Teflo to facilitate the ball drop process.

In FIG. 16d, temporary supporting layer 422 is formed over reconstituted wafer 414 and contacts a backside surface of encapsulant 286. Temporary supporting layer 422 includes high temperature tape, thermal releasable tape, and supports reconstituted wafer 414 during the formation and placement of bumps 424.

Bumps 424 are formed over reconstituted wafer 414, opposite bumps 418, and opposite temporary supporting layer 422. Bumps 424 are formed by depositing an electrically conductive bump material over conductive layer 318 using an evapo-

ration, electrolytic plating, electroless plating, ball drop, or screen printing process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to conductive layer 318 using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form spherical balls or bumps 424. In some applications, bumps 424 are reflowed a second time to improve electrical contact to conductive layer 318. The bumps can also be compression bonded to conductive layer 318. Bumps 424 represent one type of interconnect structure that can be formed over conductive layer 318. The interconnect structure can also use bond wires, conductive paste, stud bump, micro bump, or other electrical interconnect.

In another embodiment, temporary supporting layer 422 is optional and is not applied to reconstituted wafer 414 for the formation of bumps 424. Bumps 424 are formed as described above, but without temporary supporting layer 422 to provide structural support to reconstituted wafer 414. When bumps 424 are formed by a ball drop process, a chuck of the ball drop machine is used to provide temporary support during the placement of bumps 424. When used for support, the chuck of the ball drop machine is coated with compliant protecting material such as Teflo.

After the formation of bumps 424, temporary supporting layer 422, if used, is removed. Reconstituted wafer 414 is singulated with saw blade or laser cutting device 426 into individual 3-D FO-WLCSPs 428.

FIG. 17 shows 3-D FO-WLCSP 430, similar to 3-D FO-WLCSP 366 from FIG. 13x. 3-D FO-WLCSP 430 differs from FO-WLCSP 366 in that 3-D FO-WLCSP 430 is formed without the formation of openings 288 in encapsulant 286. Accordingly, a top surface 432 of conductive layer 434 is planar with top surface 436 of insulation or passivation layer 438 in a periphery of surface 432 rather than including an encapsulant 286 with a stepped configuration in a periphery of the conductive layer as shown in FIG. 13x.

FIG. 18a, similar to FIG. 13x, shows 3-D FO-WLCSP 442, similar to 3-D FO-WLCSP 366 from FIG. 13x. 3-D FO-WLCSP 442 differs from FO-WLCSP 366 in that 3-D FO-WLCSP 442 is formed with conductive columns 444 and insulation or passivation layer 446. Conductive columns 444 are formed over front side 448 of encapsulant 450, over contact pads 451 of semiconductor die 452, and within openings 453. Conductive columns 444 are formed using a patterning and metal deposition process such as sputtering, electrolytic plating, and electroless plating. In one embodiment, conductive columns 444 are Cu. Alternatively, conductive columns 444 are one or more layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable electrically conductive material. In one embodiment, conductive columns 444 include a Cu plating seed layer that is deposited with PVD over front side 448 of encapsulant 450, over contact pads 451 of semiconductor die 452, and within openings 453. Conductive columns 444 are electrically connected to contact pads 451, bumps 454, and interconnect structure 456.

Insulation layer 446 is formed over encapsulant 450, over semiconductor die 452, and around conductive columns 444, with vacuum lamination, paste printing, compression molding, spin coating, or other suitable process. Insulation layer 446 is LCP, laminate compound film, insulation paste with filler, solder mask resist film, liquid or granular molding compound, photosensitive composite resist, and photosensitive low curing temperature dielectric resist. In one embodiment, insulation layer 446 includes an optional dielectric

layer that is applied and patterned on front side 448 of encapsulant 450 after forming opening 453 in encapsulant 450. After the formation of insulation layer 446, the insulation layer undergoes curing or UV exposure, development, and curing. After curing, a portion of insulation layer 446 is removed by grinding, laser drilling, or other suitable process to expose a portion of conductive columns 444 covered by insulation layer 446.

FIG. 18b shows a 3-D FO-WLCSP 462, similar to the 3-D FO-WLCSP 442 from FIG. 18a. 3-D FO-WLCSP 462 differs from FO-WLCSP 442 in that 3-D FO-WLCSP 462 is formed without the formation of openings 453 in encapsulant 450. Accordingly, a top surface 464 of conductive layer 466 is planar with front side 468 of encapsulant 450 in a periphery of surface 464 rather than including an encapsulant with a stepped configuration in a periphery of the conductive layer as shown in FIG. 18a.

FIG. 19a, similar to FIG. 13x, includes the additional features of vias or TSVs 474 and contact pads 476. Vias 474 are formed through semiconductor die 478 by deep reactive ion etching (DRIE), laser drilling, or other suitable process. Vias 474 are filled with Al, Cu, Sn, Ni, Au, Ag, Ti, W, poly-silicon, or other suitable electrically conductive material using PVD, CVD, electrolytic plating, electroless plating, or other suitable metal deposition process. Alternatively, a plurality of stud bumps or solder balls can be formed within the vias. Vias 474 extend from contact pads 480 at an active surface of semiconductor die 478 to the backside of semiconductor die 478 to provide through vertical electrical interconnect for 3-D FO-WLCSP 482.

Contact pads or post TSV RDLs 476 are formed over vias 474 and over a backside of semiconductor die 478. Contact pads 476 are made with a conductive material, such as Al, Cu, Sn, Ni, Au, or Ag, and are electrically connected to vias 474 and contact pads 480. Contact pads 476 are formed by PVD, CVD, electrolytic plating, electroless plating, or other suitable process. Contact pads 476 are exposed when a backside or top surface of encapsulant 484 over contact pads 476 undergoes a grinding operation to planarize the surface and reduce a thickness of the encapsulant. In one embodiment, contact pads 476 are exposed by the back grinding process before the formation of openings 486. Alternatively, contact pads 476 can be exposed with shallow laser drilling or other suitable process either before or after the formation of openings 486.

FIG. 19b shows 3-D FO-WLCSP 490 similar to 3-D FO-WLCSP 482 from FIG. 19a. 3-D FO-WLCSP 490 differs from FO-WLCSP 482 with the inclusion of semiconductor die 492 mounted with microbumps 494 over a backside of semiconductor die 496. Semiconductor die 492 is mounted at a panel level, at the reconstituted wafer level, or alternatively after an SMT process.

FIG. 20a shows a 3-D FO-WLCSP 500 similar to 3-D FO-WLCSP 366 from FIG. 13x. In FIG. 20a, a backside surface of semiconductor die 502 is exposed from encapsulant 504. An encapsulant or molding compound 506 is deposited over and contacts an entire backside or top surface of semiconductor die 502 and encapsulant 504. Encapsulant 506 is deposited using vacuum lamination, paste printing, compression molding, transfer molding, liquid encapsulant molding, spin coating, spray coating or other suitable process followed by curing. Encapsulant 506 is LCP with or without Cu foil, laminate compound film, insulation paste with filler, solder mask resist film, liquid or granular molding compound, photosensitive composite resist, photosensitive low curing temperature dielectric resist, or other suitable material. Encapsulant 506 is non-conductive, provides physical sup-

port, and environmentally protects the semiconductor device from external elements and contaminants. In one embodiment, encapsulant 506 has a CTE equal to or greater than 15 ppm and is black in color. A thickness of encapsulant 506 and other material properties of encapsulant 506 are selected to obtain desired warpage and reliability performance for 3-D FO-WLCSP 500.

FIG. 20b shows 3-D FO-WLCSP 510 similar to 3-D FO-WLCSP 500 from FIG. 20a. Rather than depositing encapsulant or molding compound 506 over an entire backside or top surface of semiconductor die 502 and encapsulant 504, encapsulant 512 is deposited over a backside surface of semiconductor die 514 and a portion of encapsulant 516. However, encapsulant 512 is not formed in a periphery of openings 518. Encapsulant 512 provides physical support and environmentally protects semiconductor die 514 from external elements and contaminants. In one embodiment, encapsulant 512 has a CTE equal to or greater than 15 ppm and is black in color. A thickness of encapsulant 512 and other material properties of the encapsulant are selected to obtain desired warpage and reliability performance for 3-D FO-WLCSP 510.

FIG. 21a shows 3-D FO-WLCSP 522 similar to 3-D FO-WLCSP 366 from FIG. 13x. FO-WLCSP 522 differs from FO-WLCSP 366 in that encapsulant 524 is formed with a stepped portion 526 of encapsulant 524 that has a vertical offset 528 from a back surface of encapsulant 524 outside a footprint of semiconductor die 530. Thus stepped portion 526 forms a stepped mold cap that protrudes over a backside of semiconductor die 530. Stepped portion 526 is formed during formation of encapsulant 524. Alternatively, stepped portion 526 is formed in a selective back grinding process. Stepped portion 526 has a thickness 532 over a backside of semiconductor die 530, and in one embodiment thickness 532 is less than a thickness of semiconductor die 530. In another embodiment, thickness 532 is greater than or equal to a thickness of semiconductor die 530. Thickness 532, vertical offset 528, and a length and width of a stepped portion 526 are adjusted in order to optimize package aspect ratios and the performance of 3-D FO-WLCSP 522 in terms of thermal performance, and warpage. The length and width of stepped portion 526 are adjusted according to the design of 3-D FO-WLCSP 522 to form an area that is larger than a footprint of semiconductor die 530. Alternatively, the length and width of stepped portion 526 are adjusted to form an area that is smaller than or equal to a footprint of semiconductor die 530. In one embodiment, an outer edge of stepped portion 526 is vertically aligned with an outer edge of semiconductor die 530.

FIG. 21b shows 3-D FO-WLCSP 538 similar to the 3-D FO-WLCSP 522 from FIG. 21a. Encapsulant 540 has a vertical offset 542 with respect to a back surface of encapsulant 540 outside a footprint of semiconductor die 544. Thus, vertical offset 542 forms a stepped mold cap that protrudes over a backside of semiconductor die 544. Vertical offset 542 is formed during formation of encapsulant 540. Alternatively, vertical offset 542 is formed in a selective back grinding process. A semiconductor device or package 546 is mounted over semiconductor die 544 and is electrically connected to conductive layer 548 with bumps 550. A bottom surface of semiconductor device 546 has a vertical offset 552 with respect to a back surface of encapsulant 540 outside a footprint of semiconductor die 544. A distance of vertical offset 552 is greater than a distance of vertical offset 542 such that the bottom surface of semiconductor device 546 does not contact a back surface of encapsulant 540, including a back surface of the stepped mold cap.

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FIG. 21c shows 3-D FO-WLCSP 556 similar to 3-D FO-WLCSP 538 from FIG. 21b. Encapsulant 558 has a vertical offset 560 with respect to a top or backside surface of encapsulant 558 that forms a cavity 561 in the encapsulant over a backside of semiconductor die 562. Vertical offset 560 forms cavity 561 that is recessed with respect to, and is lower than, the top or backside surface of encapsulant 558 outside a footprint of the cavity. Cavity 561 is formed during formation of encapsulant 558. Alternatively, cavity 561 is formed in a selective back grinding process, by shallow laser grooving, wet etching, or other suitable method. Cavity 561 is configured to provide space for a later mounted semiconductor device such as a flip chip semiconductor device, bond wire BGA, bond wire LGA, discrete component, or other semiconductor device.

A semiconductor device or package 564 is mounted over semiconductor die 562 and is electrically connected to conductive layer 566 with bumps 568. A bottom surface of semiconductor device 564 has a vertical offset 570 with respect to a top or backside surface of encapsulant 558. A semiconductor device or package 572 is mounted to semiconductor device 564 and is between bumps 568. A combined distance of vertical offset 560 and 570 is greater than a vertical distance occupied by semiconductor device 572. Accordingly, semiconductor device 572 fits within cavity 561 and is positioned over and does not contact encapsulant 558.

FIG. 22a shows 3-D FO-WLCSP 576 similar to 3-D FO-WLCSP 366 from FIG. 13v. However, FO-WLCSP 576 does not include the formation of electrical interconnects or bumps similar to bumps 356 in FO-WLCSP 366 for top side electrical interconnection. Electrical interconnects within openings 578 are not formed prior to completion of 3-D FO-WLCSP 576. Instead, an electrical interconnect is formed in openings 578 during an SMT process for next level interconnection, or as part of a PoP assembly process, after completion of 3-D FO-WLCSP 576.

FIG. 22b, similar to FIG. 22a, shows another embodiment in which electrical interconnects or bumps similar to bumps 356 in FO-WLCSP 366 are not formed until after completion of 3-D FO-WLCSP 580. Electrical interconnects are formed in openings 582 during an SMT process for next level interconnection, or as part of a PoP assembly process. In contrast with FIG. 22a, FIG. 22b shows a backside of semiconductor die 584 is exposed from encapsulant 586 as part of singulated 3-D FO-WLCSP 580.

FIG. 22c, similar to FIG. 22b, shows FO-WLCSP 590 with conductive layer 592 formed over, or on, a top or backside surface of encapsulant 594 and over a backside of semiconductor die 596. Conductive layer or film 592 is Cu, Al, ferrite or carbonyl iron, stainless steel, nickel silver, low-carbon steel, silicon-iron steel, foil, conductive resin, and other material with high thermal conductivity or capable of blocking or absorbing electromagnetic interference (EMI), radio frequency interference (RFI), harmonic distortion, and other inter-device interference. Conductive layer 592 is patterned and conformally deposited using a lamination, printing, electrolytic plating, electroless plating, sputtering, PVD, CVD, or other suitable metal deposition process. Conductive layer 592 can be formed with an optional insulation or protection layer 596.

Optional insulation layer 596 is formed over a backside of semiconductor die 596. Insulation layer 596 contains one or more layers of photosensitive low curing temperature dielectric resist, photosensitive composite resist, LCP, laminate compound film, insulation paste with filler, solder mask resist film, liquid molding compound, granular molding compound, polyimide, BCB, PBO, SiO₂, Si₃N₄, SiON, Ta₂O₅,

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Al₂O₃, or other material having similar insulating and structural properties. Insulation layer 596 is deposited using printing, spin coating, spray coating, vacuum or pressure lamination with or without heat, or other suitable process.

Conductive layer 592 and optional insulation layer 596 can be formed on the backside of encapsulant 594 and semiconductor die 596 before or after the formation of openings 598. In one embodiment, conductive layer 592 acts as a heat sink to improve thermal performance of 3-D FO-WLCSP 590. In another embodiment, conductive layer 592 acts as a shielding layer for blocking or absorbing EMI, RFI, harmonic distortion, and other interference.

FIG. 23 shows a 3-D FO-WLCSP 600, similar to 3-D FO-WLCSP 362 from FIG. 13w. 3-D FO-WLCSP 600 differs from FO-WLCSP 362 by the inclusion of crack stop layer 602. Crack stop layer 602 is conformally applied over, and follows the contours of, insulation layer 604 over semiconductor die 606 with spin coating, vacuum or pressure lamination with or without heat, screen printing, or other suitable process. Crack stop layer 602 contains one or more layers of SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, HfO₂, photosensitive polyimide, non-photosensitive polyimide, BCB, PBO, dielectric film material, or other material having similar insulating and structural properties with a curing temperature of less than or equal to 380° C. Crack stop layer 602 has a high tensile strength and high elongation that aids in the prevention of cracks within 3-D FO-WLCSP 600. In one embodiment, crack stop layer 602 has a tensile strength greater than or equal to 100 megapascals (MPa) and an elongation in the range of 30-150%. A portion of crack stop layer 602 is removed from over contact pads 277 by laser drilling, reactive ion etching (RIE), UV exposure, or other suitable process to form an opening or via which exposes a portion of contact pads 277. The portion of crack stop layer 602 removed from over contact pads 277 is removed after the curing of the crack stop layer, or alternatively, is removed before semiconductor die 606 is singulated and subsequently mounted within a portion of 3-D FO-WLCSP 600. In one embodiment, a portion of insulation layer 604 is also removed in a same process step as the removal of the portion of crack stop layer 602 in order to expose the portion of contact pads 277.

FIG. 24a shows a 3-D FO-WLCSP 610, similar to 3-D FO-WLCSP 362 from FIG. 13w. 3-D FO-WLCSP 610 differs from FO-WLCSP 362 by inclusion of an interconnect structure 612 that is expanded horizontally with respect to interconnect 320. Interconnect structure 612 includes conductive layer 614, similar to conductive layer 302, that extends into openings or voids 616 and 618 in encapsulant 620. Openings 616 and 618 are analogous to openings 288 in FIG. 13h, and are formed in a front side of encapsulant 620. Openings 624 are analogous to openings 350 from FIG. 13i, and are formed in a backside of encapsulant 620 and over openings 616. Openings 624 are not formed over openings 618. Accordingly, not every opening 616 and 618 formed in the front side of encapsulant 620 will have a corresponding opening 624 formed in the backside of encapsulant 620. Openings 618 that do not have a corresponding opening 624 formed in the backside of encapsulant 620 are positioned within 3-D FO-WLCSP 610 such that bump or front side I/O interconnects 628 are formed over, and vertically aligned with, openings 618. The number and configuration of conductive and insulation or passivation layers included within interconnect structure 612 varies with the complexity of circuit routing design according to the design and function of 3-D FO-WLCSP 610, and provides additional interconnect capabilities.

FIG. 24*b*, similar to FIG. 24*a*, shows FO-WLCSP 632 with a horizontally expanded interconnect structure 634 that extends into openings 636, 638, and 640. Conductive layer 642 is conformally applied to, and follows the contours of, insulation or passivation layer 644. Conductive layer 642 extends into openings 636, but does not extend into openings 638 and 640. Opening 638 does not have a corresponding opening 644 formed in the backside of encapsulant 646, and is positioned within 3-D FO-WLCSP 632 such that a bump or front side I/O interconnect 648 is formed over, and is vertically aligned with, opening 638. A portion of conductive layer 642, while not extending into opening 638, does extend between opening 638 and interconnect 648. Similarly, opening 640 does not have a corresponding opening 644 formed in the backside of encapsulant 646, but is positioned within 3-D FO-WLCSP 632 such that a bump or front side I/O interconnect 648 is formed over, and is horizontally aligned with, opening 640. A portion of conductive layer 642 does not extend between opening 640 and interconnect 648. The number and configuration of conductive and insulation or passivation layers within interconnect 634 varies with the complexity of circuit routing design according to the design and function of 3-D FO-WLCSP 632.

FIG. 25*a*, similar to FIG. 24*a*, shows 3-D FO-WLCSP 652 with a horizontally expanded interconnect structure 654. 3-D FO-WLCSP 652 includes encapsulant layer 656 with openings or voids 658 formed in multiple rows on a front side of the encapsulant layer. Interconnect structure 654 is formed over the front side of encapsulant 654 and a portion of the interconnect structure extends into openings 658. Conductive layer 660 is formed as a portion of interconnect structure 654 and is conformally applied to, and follows the contours of, insulation or passivation layer 662. Conductive layer 660 extends into openings 658, and each opening 658 has a corresponding opening 664 formed in the backside of encapsulant 656. Accordingly, openings 664 are formed in multiple rows and are positioned as an array for vertical electrical connection through the backside of FO-WLCSP 652. Electrical connection through openings 664 is accomplished by depositing conductive material within the openings and on interconnect structure 654 as previously described. Openings 658 are positioned within 3-D FO-WLCSP 652 such that a bump or front side I/O interconnect 668 is formed over, and is vertically aligned with, each opening 658. The number and configuration of conductive and insulation or passivation layers within interconnect 654 varies with the complexity of circuit routing design and according to the design and function of 3-D FO-WLCSP 652. Accordingly, 3-D FO-WLCSP 652 provides 3-D electrical interconnection with an interconnect I/O array through vertical interconnects formed outside a footprint of semiconductor die 670 without the use of a backside RDL that extends within a footprint of the semiconductor die.

FIG. 25*b*, similar to FIG. 25*a*, shows 3-D FO-WLCSP 674 with a horizontally expanded interconnect structure 676. 3-D FO-WLCSP 674 differs from FO-WLCSP 652 in that a thin layer of insulation or passivation 678 remains in opening 680 between opening 684 formed in a backside of encapsulant 682 and conductive layer 686. In one embodiment insulation layer 678 is underdeveloped such that the thin layer of insulation layer 678 remains in opening 680. Accordingly, 3-D FO-WLCSP 674 provides 3-D electrical interconnection with an interconnect I/O array through vertical interconnects formed outside a footprint of semiconductor die 686 without the use of a backside RDL that extends within a footprint of the semiconductor die.

FIGS. 26*a*-26*q*, continuing from FIG. 13*b*, illustrate another process of forming an interconnect structure for a 3-D FO-WLCSP. In FIG. 26*a*, semiconductor die 276 is mounted over carrier 270 with an active surface 688 of the semiconductor die oriented toward substrate 270 and interface layer 272. Semiconductor die 276 may include discrete devices. Discrete devices can be active devices, such as transistors and diodes, or passive devices, such as capacitors, resistors, and inductors for RF signal processing. Additionally, discrete devices may be mounted over carrier 270. Carrier 270 may be round, rectangular, square, or any shape useful for forming a FO-WLCSP. In one embodiment, surface 690 is embedded within interface layer 272 after mounting semiconductor die 276 to carrier 270. Surface 690 of insulation layer 278 is embedded within interface layer 272 and surface 690 is vertically offset from a surface of interface layer 272 opposite carrier 270. A portion of interface layer 272 covers a sidewall 694 of insulation layer 278. Active surface 688 of semiconductor die 276 is coplanar with the surface of interface layer 272 opposite carrier 270. In an alternative embodiment, semiconductor die 276 is positioned over interface layer 272 such that surface 690 of insulation layer 278 is coplanar with the surface of interface layer 272 opposite carrier 270.

An encapsulant or molding compound 696 is deposited over semiconductor die 276, interface layer 272, and carrier 270 using a paste printing, compressive molding, transfer molding, liquid encapsulant molding, vacuum or pressure lamination with or without heat, spin coating, or other suitable applicator. Encapsulant 696 can be polymer composite material, such as epoxy resin with filler, epoxy acrylate with filler, or polymer with proper filler. Encapsulant 696 is non-conductive and environmentally protects the semiconductor device from external elements and contaminants. Surface 690 of insulation layer 278 is vertically offset from surface 692, the surface of encapsulant 696 contacting interface layer 272. Thus, surface 692 of encapsulant 696 and surface 690 of insulation layer 278 are non-planar. In an alternative embodiment, semiconductor die 276 is positioned over interface layer 272 such that surface 690 of insulation layer 278 is coplanar with surface 692 of encapsulant 696.

In FIG. 26*b*, carrier 270 and interface layer 272 are removed by chemical etching, mechanical peeling, CMP, mechanical grinding, thermal bake, UV light, laser scanning, or wet stripping to expose conductive layer 277, insulation layer 278, and encapsulant 696. Encapsulant 696 provides structural support for semiconductor die 276 after removal of carrier 270.

An insulating or passivation layer 700 is formed over encapsulant 696 and insulating layer 134 using PVD, CVD, printing, spin coating, spray coating, screen printing, or vacuum or pressure lamination with or without heat. Insulating layer 700 contains one or more layers of photosensitive polymer dielectric film with or without fillers, non-photosensitive polymer dielectric film with or without fillers, SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, prepreg, or other material having similar insulating and structural properties. In one embodiment, insulating layer 700 is a composite material including polymer and a reinforcement fiber, filler, woven fiber, or woven glass. In an alternative embodiment, insulating layer 700 is a composite material including a prepreg material and a resin, such as epoxy-based resin, the resin enhanced with woven fiber, cloth, glass, or woven glass. The CTE for insulating layer 700 is selected to be 70 ppm or less. Insulating layer 700 has a thickness of 40 μm or less.

In FIG. 26*c*, a portion of insulating layer 700 is removed by an etching process with a patterned photoresist layer, developing with a chemical process, or other suitable process to

create vias or openings 702 to expose conductive layer 277. Alternatively, insulating layer 700 is non-photosensitive and a portion of insulating layer 700 is removed by laser direct ablation (LDA) using laser 704 to create vias 702 to expose conductive layer 277. Additionally, a portion of insulating layer 700 outside a footprint of semiconductor die 276 is removed by an etching process with a patterned photoresist layer, developing with a chemical process, or other suitable process to create micro vias or openings 706. Alternatively, a portion of insulating layer 700 is removed by LDA using laser 708 to create micro vias 706. After forming openings 702 and micro vias 706, openings 702 and micro vias 706 undergo a desmearing or cleaning process. In an alternative embodiment, a protection layer is applied over insulating layer 700 prior to forming openings 702 and micro vias 706. The protection layer is subsequently removed after forming openings 702 and micro vias 706 and can be removed during the desmearing process. A suitable material for insulating layer 700 has a resolution capable of providing openings 702 and micro vias 706 with a diameter of 10 μm or less, thereby providing high-resolution electrical re-routing. In one embodiment, insulating layer 700 is black or dark in color to provide better laser absorption during LDA. Alternatively, insulating layer 700 is a color other than black or is optically transparent or translucent.

Micro vias 706 can have a straight, sloped, stepped, or tapered sidewall. In one embodiment, micro vias 706 have a cross-sectional width or diameter ranging from 10-100 μm . In another embodiment, micro vias 706 have a cross-sectional width or diameter ranging from 20-30 μm . A plurality of micro vias 706 are formed outside a footprint of semiconductor die 276 and in a peripheral region or area of semiconductor die 276 in an array or group of micro vias 706 to form a micro via array 710. Micro via array 710 contains one or more micro vias 706. Micro via array 710 extends from a first surface 712 of insulating layer 700 to a second surface 714 of insulating layer 700 opposite first surface 712. Micro via array 710 exposes surface 692 of encapsulant 696 outside a footprint of semiconductor die 276.

In FIG. 26d, an electrically conductive layer 720 is formed over insulating layer 700, encapsulant 696, and semiconductor die 276 using a patterning and metal deposition process, such as PVD, CVD, electrolytic plating, or electroless plating process. Conductive layer 720 can be one or more layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable electrically conductive material. Individual portions of conductive layer 720 can be electrically common or electrically isolated according to the design and function of semiconductor die 276. A portion of conductive layer 720 extends through vias 702 to electrically connect conductive layer 720 to conductive layer 277. A portion of conductive layer 720 extends horizontally along insulating layer 700 and parallel to active surface 688 of semiconductor die 276 to laterally redistribute the electrical interconnect to conductive layer 277 of semiconductor die 276. Conductive layer 720 operates as a fan-out redistribution layer (RDL), providing lateral or horizontal redistribution for the electrical signals of semiconductor die 276.

A portion of conductive layer 720 also extends through micro vias 706 to form conductive micro vias 722. Conductive micro vias 722 extend from the horizontal portion of conductive layer 722, through insulating layer 700, to surface 692 of encapsulant 696. Conductive micro vias 722 can have straight, sloped, tapered, or stepped sidewalls. In one embodiment, conductive micro vias 722 have a generally conical shape with a generally circular cross-section. In another embodiment, conductive micro vias 722 have a generally cylindrical shape with a generally circular cross-section. In

another embodiment, conductive micro vias 722 have a generally cubic shape with a generally rectangular cross-section. The shape of conductive micro vias 722 can vary according to the design and function of semiconductor die 276. In one embodiment, conductive micro vias 722 have a cross-sectional width or diameter ranging from 10-100 μm . In another embodiment, conductive micro vias 722 have a cross-sectional width or diameter ranging from 20-30 μm .

Conductive micro vias 722 are formed in a peripheral region or area of semiconductor die 276, outside a footprint of semiconductor die 276, as a group or array of multiple conductive micro vias 722 to form a conductive micro via array 724. Conductive micro vias 722, within conductive micro via array 724, form a series of peaks and valleys of conductive layer 720, providing a greater surface area for contact between conductive layer 720 and a subsequently formed conductive interconnect structure.

FIG. 26e shows a plan view of the assembly from FIG. 26d, from a plane that runs parallel to active surface 688 of semiconductor die 276 and the horizontal portion of conductive layer 720, along surface 714 of insulating layer 700, and surface 692 of encapsulant 696. A plurality of conductive micro vias 722a-722g is formed outside a footprint of semiconductor die 276 and extends through insulating layer 700 to encapsulant 696. In particular, conductive micro vias 722a-722f are formed in a generally circular or hexagonal shape or pattern around a central conductive micro via 722g. Conductive micro via 722g is centrally located relative to conductive micro vias 722a-722f. Conductive micro vias 722a-722f are positioned at the corners of a hexagon shape in a peripheral region of the central conductive micro via 722g. Each conductive micro via 722a-722f is an equal distance from conductive micro via 722g. Conductive micro vias 722a-722f are also an equal distance from each adjacent conductive micro via 722a-722f.

Collectively, conductive micro vias 722a-722g constitute conductive micro via array 724. In one embodiment, conductive micro via array 724 has fewer or additional conductive micro vias 722, according to the design and function of semiconductor die 276. In another embodiment, conductive micro vias 722 are arranged in different patterns or arrangements within conductive micro via array 724, for example, columns or rows of multiple conductive micro vias 722.

FIG. 26f illustrates another embodiment of a conductive micro via array including a conductive ring formed around the micro via array. Continuing from FIG. 26c, a portion of insulating layer 700 between or outside a footprint of semiconductor die 276, and around a perimeter of micro via array 710, is removed by an etching process with a patterned photoresist layer to create trench 726. Trench 726 is formed around micro vias 706 prior to depositing conductive layer 720. Alternatively, a portion of insulating layer 700 is removed by LDA using a laser to create trench 726. Trench 726 can have a straight, sloped, stepped, or tapered sidewall. A footprint of trench 726 can vary in shape, according to the design and function of semiconductor die 276. For example, the footprint of trench 726 can be generally circular or rectangular around micro vias 706.

A portion of conductive layer 720 extends through trench 726 to form conductive ring 730. Conductive micro vias 722 and conductive ring 730 extend from the horizontal portion of conductive layer 720, to surface 692 of encapsulant 696. Conductive micro vias 722 and conductive ring 730 can have straight, sloped, tapered, or stepped sidewalls. Conductive micro vias 722 are formed in a peripheral region or area of semiconductor die 276, outside a footprint of semiconductor die 276, as a group or array of multiple conductive micro vias

722 surrounded by conductive ring 730 to form conductive micro via array 732. Conductive micro vias 722 and conductive ring 730, within conductive micro via array 732, constitute a series of peaks and valleys of conductive layer 720, providing a greater surface area for contact between conductive layer 720 and a subsequently formed conductive interconnect structure.

FIG. 26g shows a top or plan view of the assembly from FIG. 26f, from a plane that runs parallel to active surface 688 of semiconductor die 276 and the horizontal portion of conductive layer 720, along surface 714 of insulating layer 700, and surface 692 of encapsulant 696. Conductive ring 730 is formed around conductive micro vias 722a-722g, in a peripheral area of conductive micro vias 722a-722g. Conductive ring 730 has a footprint that is generally circular, with conductive micro via 722g at the center of conductive ring 730 and conductive micro vias 722a-722f an equal distance from conductive ring 730. The shape of conductive ring 730 can vary according to the design and function of semiconductor die 276. Conductive micro vias 722a-722g and conductive ring 730 constitute a conductive micro via array 732. In one embodiment, conductive micro vias 722a-722g and conductive ring 730 have tapered sidewalls. In another embodiment, conductive micro vias 722a-722g and conductive ring 730 have straight, sloped, curved, or stepped sidewalls.

Continuing from FIG. 26d, an insulating or passivation layer 734 is formed over conductive layer 720 and insulating layer 700 using PVD, CVD, printing, spin coating, spray coating, screen printing, or vacuum or pressure lamination with or without heat, as shown in FIG. 26h. Insulating layer 734 contains one or more layers of photosensitive polymer dielectric film with or without fillers, non-photosensitive polymer dielectric film with or without fillers, SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, prepreg, or other material having similar insulating and structural properties. In one embodiment, insulating layer 734 is a composite material including polymer and a reinforcement fiber, filler, woven fiber, or woven glass. In an alternative embodiment, insulating layer 734 is a composite material including a prepreg material and a resin, such as epoxy-based resin, the resin enhanced with woven fiber, cloth, glass, or woven glass. The CTE for insulating layer 734 is selected to be 70 ppm or less.

A portion of insulating layer 734 is removed by an etching process with a patterned photoresist layer, developing with a chemical process, or other suitable process to create vias or openings 736 and to expose conductive layer 720. Alternatively, a portion of insulating layer 734 is removed by LDA using laser 738 to create vias 736 and to expose conductive layer 720. In one embodiment, insulating layer 734 is black or dark in color to provide better laser absorption during LDA. Alternatively, insulating layer 734 is a color other than black or is optically transparent or translucent. A suitable material for insulating layer 734 has a resolution capable of providing openings 736 with a diameter of 30 μm or less. Insulating layer 734 can have a thickness equal to, less than, or greater than a thickness of insulating layer 700, according to the design and function of semiconductor die 276. In one embodiment, insulating layer 734 has a thickness of 40 μm or less. Insulating layer 734 provides openings for electrical routing and provides physical support for the FO-WLCSP device.

In FIG. 26i, an electrically conductive layer 740 is formed over insulating layer 734 and conductive layer 720 using patterning with PVD, CVD, sputtering, electrolytic plating, electroless plating process, or other suitable metal deposition

process. Conductive layer 740 is electrically connected to conductive layer 720. A portion of conductive layer 740 extends horizontally along insulating layer 734 and parallel to active surface 688 of semiconductor die 276 to laterally redistribute the electrical interconnect to conductive layer 720. Conductive layer 740 operates as a fan-out RDL for the electrical signals of semiconductor die 276. Other portions of conductive layer 740 are electrically common or electrically isolated depending on the connectivity of semiconductor die 276.

An insulating or passivation layer 742 is formed over insulating layer 734 and conductive layer 740 using PVD, CVD, printing, spin coating, spray coating, screen printing, or vacuum or pressure lamination with or without heat. Insulating layer 742 contains one or more layers of photosensitive polymer dielectric film with or without fillers, non-photosensitive polymer dielectric film with or without fillers, SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, prepreg, or other material having similar insulating and structural properties. In one embodiment, insulating layer 742 is a composite material including polymer and a reinforcement fiber, filler, woven fiber, or woven glass. In an alternative embodiment, insulating layer 742 is a composite material including a prepreg material and a resin, such as epoxy-based resin, the resin enhanced with woven fiber, cloth, glass, or woven glass. A suitable material for insulating layer 742 has good adhesion and hardness at a temperature of 260° C. or higher. The CTE for insulating layer 742 is selected to be 70 ppm or less.

A portion of insulating layer 742 is removed by UV exposure, an etching process with a patterned photoresist layer, developing with a chemical process, or other suitable process to create openings 744 and to expose conductive layer 740. Alternatively, a portion of insulating layer 742 is removed by LDA using laser 746 to create openings 744 and to expose conductive layer 740. In one embodiment, insulating layer 742 is black or dark in color to provide better laser absorption during LDA. Alternatively, insulating layer 742 is a color other than black or is optically transparent or translucent. The thickness and material of insulating layer 742 can vary according to the design and function of semiconductor die 276. The thickness of insulating layer 742 can be less than or equal to the thickness of insulating layer 700. Alternatively, the thickness of insulating layer 742 can be greater than the thickness of insulating layer 700 to provide additional structural support, balance, stress relief, and warpage control to the package. In one embodiment, insulating layer 742 has a thickness of 40 μm or less and includes a high glass transition temperature of over 260° C. Insulating layer 742 provides environmental protection and structural support for the FO-WLCSP device.

In FIG. 26j, an electrically conductive bump material is deposited over the exposed conductive layer 740 using an evaporation, electrolytic plating, electroless plating, ball drop, or screen printing process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to conductive layer 740 using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form balls or bumps 750. In some applications, bumps 750 are reflowed a second time to improve electrical contact to conductive layer 740. A UBM layer can be formed under bumps 750. Bumps 750 can also be compression bonded to conductive layer 740. Bumps 750 represent one type of conductive interconnect structure that

can be formed over conductive layer 740. The interconnect structure can also use stud bump, micro bump, or other electrical interconnect.

Collectively, insulating layers 700, 734, and 742, conductive layers 720 and 740, and bumps 750 constitute a build-up interconnect structure 752 formed over semiconductor die 276 and encapsulant 696 with conductive micro via array 724 formed outside a footprint of semiconductor die 276. Build-up interconnect structure 752 may include as few as one RDL or conductive layer, such as conductive layer 720. Additional insulating layers and RDLs can be formed over insulating layer 742 prior to forming bumps 750, to provide additional vertical and horizontal electrical connectivity across the package according to the design and functionality of semiconductor die 276.

In FIG. 26k, back grinding tape 754 is applied over semiconductor die 276, encapsulant 696, and build-up interconnect structure 752 using lamination or other suitable application process. Back grinding tape 754 contacts insulating layer 742 and bumps 750. Back grinding tape 754 follows the contours of a surface of bumps 750 and extends around and between bumps 750. Back grinding tape 754 includes tapes with thermal resistance up to 270° C. Back grinding tape 754 also includes tapes with a thermal release function. Examples of back grinding tape 754 include UV tape HT 440 and non-UV tape MY-595. Back grinding tape 754 provides structural support for subsequent back grinding and removal of a portion of encapsulant 696 from a backside surface 762 of encapsulant 696, opposite build-up interconnect structure 752. An additional support layer 756 is applied to back grinding tape 754 for additional structural support during back grinding. Support layer 756 may comprise a substrate or carrier and may include resin, sacrificial base material such as silicon, polymer, beryllium oxide, or other suitable low-cost, rigid material for structural support.

Backside surface 762 of encapsulant 696 undergoes a grinding operation with grinder 760 to planarize and reduce a thickness of encapsulant 696. A chemical etch can also be used to remove and planarize encapsulant 696. After the grinding operation is completed, a back surface of semiconductor die 276 is exposed. A thickness of semiconductor die 276 can also be reduced by the grinding operation. Alternatively, a thickness of encapsulant 696 maintains coverage over a back surface of semiconductor die 276. After the grinding operation, encapsulant 696 has a thickness T1, measured from surface 692 of encapsulant 696 to exposed backside surface 762 of encapsulant 696. In one embodiment, thickness T1 of encapsulant 696 is between 100-250 μm. Back grinding tape 754 and support layer 756 can be actively cooled during the grinding operation.

In FIG. 26l, an insulating or passivation layer 764 is formed over exposed backside surface 762 of encapsulant 696 and a back surface of semiconductor die 276 using PVD, CVD, printing, spin coating, spray coating, screen printing, or vacuum or pressure lamination with or without heat. Insulating layer 764 contains one or more layers of photosensitive polymer dielectric film with or without fillers, non-photosensitive polymer dielectric film, SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, or other material having similar insulating and structural properties. Insulating layer 764 operates as a backside protection and balancing layer, providing environmental protection for the semiconductor device from external elements and contaminants. Additionally, insulating layer 764 provides structural support for the package, to balance stress on the package, and reduce warping or cracking of the package during subsequent handling and processing. Accordingly, in one embodiment, insulating layer 764 has a CTE similar or

equal to insulating layer 742 or encapsulant 696. Insulating layer 764 can have a thickness equal to, less than, or greater than a thickness of insulating layer 742, according to the design and function of semiconductor die 276. In one embodiment, insulating layer 764 has a thickness ranging from 20-75 μm.

FIG. 26m shows a composite substrate or reconstituted wafer 766 covered by encapsulant 696. Reconstituted wafer 766 may be round, rectangular, square, or another shape. In FIG. 26m, a portion of encapsulant 696 is removed in a peripheral region of semiconductor die 276, over conductive micro via array 724, to form openings 770 and to expose conductive layer 720 and conductive micro via array 724. Openings 770 are formed by drilling, high energy water jetting, an etching process with a patterned photoresist layer, developing with a chemical process, or other suitable process. Alternatively, a portion of encapsulant 696 is removed in a peripheral region of semiconductor die 276 over conductive micro via array 724 by LDA using laser 772 to form openings 770. After forming openings 770, openings 770 undergo a desmearing or cleaning process, including a particle and organic residue wet clean, such as a single wafer pressure jetting clean with a suitable solvent, or alkali and carbon dioxide bubbled deionized water, in order to remove any particles or residue from the drilling process.

Openings 770 have a vertical or sloped sidewall 774 and extend through backside surface 762 of encapsulant 696 and insulating layer 764 to conductive micro via array 724. Openings 770 each constitute a through-mold-hole (TMH). In one embodiment, openings 770 have a cross-sectional width ranging from 180-450 μm. In another embodiment, openings 770 have a cross-sectional width ranging from 50-150 μm. Openings 770 may include sloped sidewalls and have a first diameter or cross-sectional width within openings 770, ranging from 50-150 μm, and a second diameter or cross-sectional width within openings 770, ranging from 180-450 μm. Alternatively, openings 770 may have a stepped sidewall resulting from the process of forming a first opening through encapsulant 696 and forming a second opening through encapsulant 696 in a footprint of the first opening, where the second opening has a cross-sectional width less than the cross-sectional width of the first opening. Openings 770 with a step-through-hole structure increase structural support and reduce damage to the package, including build-up interconnect structure 752, during processing, for example, during a desmearing process, solder capping, or a package-on-package stack soldering process.

The process of forming openings 770 further includes removing a portion of insulating layer 700 covering conductive micro via array 724. Thus, openings 770 expose conductive micro via array 724 and conductive micro vias 722 of conductive layer 720 through encapsulant 696 and insulating layer 700. The exposed conductive micro via array 724 provides a greater exposed surface area for conductive layer 720 than if the exposed portion of conductive layer 720 were flat or planar. Conductive micro via array 724 thereby provides greater contact surface area between conductive layer 720 and subsequently deposited conductive bump material, for improved and more robust electrical and mechanical contact between subsequently deposited conductive bump material and conductive layer 720. Conductive micro vias 722 also increase the effective thickness of conductive layer 720 within a footprint of conductive micro via array 724 without significantly adding to the amount of conductive material within conductive layer 720.

The assembly, reconstituted wafer 766, may be actively cooled during the formation of openings 770 to avoid strip-

ping back grinding tape 754, and to minimize the thermal impact on semiconductor die 276. In another embodiment, the assembly is not actively cooled during the formation of openings 770, but the laser source or drilling sequence parameters are optimized to minimize thermal impact on semiconductor die 276. Alternatively, back grinding tape 754 is removed after completing the back grinding of encapsulant 696, but before forming openings 770, and a supporting tape with high thermal conductivity and high heat resistance is applied over insulating layer 742 and bumps 750. The assembly mounted to a supporting tape can be actively cooled to avoid stripping the supporting tape and to minimize the thermal impact on semiconductor die 276. In another embodiment, reconstituted wafer 766 can be placed in a supporting jig to support reconstituted wafer 766 and minimize the thermal impact on semiconductor die 276. The supporting jig includes a compliant top layer to avoid structural damage to insulating layer 742 and bumps 750, prior to forming openings 770. The supporting jig has high thermal conductivity and an array of small vacuum holes to provide thermal protection and structural support for reconstituted wafer 766 during the formation of openings 770.

In FIG. 26n, an electrically conductive bump material is deposited over the exposed conductive layer 720 and conductive micro vias 722 using an evaporation, electrolytic plating, electroless plating, ball drop, screen printing, jetting, or other suitable process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to conductive layer 720 using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form spherical balls or bumps 776. In some applications, bumps 776 are reflowed a second time to improve electrical contact to conductive layer 720. A UBM layer can be formed under bumps 776. The bumps can also be compression bonded to conductive layer 720.

Bumps 776 represent one type of conductive interconnect structure that can be formed over conductive layer 720. The conductive interconnect structure can also use bond wires, Cu, Ag, or other conductive paste, stud bump, micro bump, solder balls with a Cu core, Cu balls or columns with dipped solder paste or solder coating, or other electrical interconnect. Bumps 776 are formed over conductive layer 720 and over and between conductive micro vias 722 of conductive micro via array 724. Accordingly, a 3-D interconnection for next level interconnection is formed through bumps 776, conductive layer 720, build-up interconnect structure 752, and semiconductor die 276. The 3-D interconnection provides vertical electrical interconnection without a backside interconnect or RDL formed over a footprint of semiconductor die 276. Conductive micro vias 722 provide an increased contact surface area between conductive layer 720 and bumps 776 for improved and more robust mechanical and electrical connection between conductive layer 720 and bumps 776.

In FIG. 26o, back grinding tape 754 and support layer 756 are removed after forming bumps 776. Alternatively, back grinding tape 754 and support layer 756 are removed after completing the back grinding of encapsulant 696, but before forming openings 770, and a supporting tape with high thermal conductivity and high heat resistance is applied over insulating layer 742 and bumps 750. Reconstituted wafer 766 can also be placed in a supporting jig, with a compliant top layer to avoid structural damage, prior to forming openings 770. The supporting jig has high thermal conductivity and an

array of small vacuum holes to provide thermal protection and structural support for reconstituted wafer 766 during the formation of openings 770.

In FIG. 26o, the assembly from FIG. 26n is singulated through insulating layer 764, encapsulant 696, and insulating layers 700, 734, and 742 with saw blade or laser cutting tool 780 into individual FO-WLCSPs 782.

FIG. 26p shows an individual FO-WLCSP 782 after singulation. FO-WLCSP 782 provides 3-D electrical interconnection with a fan-out RDL and conductive micro via array 724 formed outside a footprint of a semiconductor die 276. Laser drilling or other suitable method is used to form an opening in a front side of the encapsulant in a periphery of the active surface of the semiconductor die. An interconnect structure is formed over the active surface of the semiconductor die and extends into the openings in the front side of the encapsulant. The interconnect structure includes insulation and conductive layers that form a FO-WLCSP RDL. Insulating layers can be selected to provide openings or structural support or both. Elements that would otherwise be included in a backside interconnect structure or RDL can be integrated as part of a single interconnect structure formed over the active surface of the semiconductor die. Alternatively, backside RDL elements can be included in other later mounted components of another semiconductor device as part of a POP configuration. Conductive micro via array 724 formed outside a footprint of semiconductor die 276 and exposed through encapsulant 696 provides an increased surface area for bump 776 to adhere to conductive layer 720. Conductive micro via array 724 results in improved and more robust electrical and mechanical contact between FO-WLCSP 782 and other semiconductor devices.

FIG. 26q shows an alternative embodiment of the 3-D FO-WLCSP with the backside protection and balancing layer removed. In FO-WLCSP 784, insulating layer 764 is partially or completely removed by mechanical grinding, by LDA, or by another suitable process after the formation of build-up interconnect structure 752, to expose a back surface of semiconductor die 276 and a backside surface 762 of encapsulant 694. Alternatively, FO-WLCSP 784 is formed in a process similar to 26a-26o, but FO-WLCSP 784 is formed without insulating layer 764.

FIG. 27 illustrates an alternative embodiment of the 3-D FO-WLCSP including a vertical interconnect structure and multiple semiconductor die. FO-WLCSP 786 includes two or more semiconductor die 276 disposed side-by-side within the 3-D FO-WLCSP structure. FO-WLCSP 786 is formed by the process shown in FIGS. 26a-26p with two semiconductor die 276 disposed side-by-side between openings 770 in encapsulant 696. In FIG. 27, an encapsulant 696 is deposited over semiconductor die 276. An insulating layer 700 is formed over active surface 688 of semiconductor die 276 and surface 692 of encapsulant 696. In one embodiment, insulating layer 700 is a composite material including polymer and a reinforcement fiber, filler, woven fiber, or woven glass. In an alternative embodiment, insulating layer 700 is a composite material including a prepreg material and a resin, such as epoxy-based resin, the resin enhanced with woven fiber, cloth, glass, or woven glass. The CTE for insulating layer 700 is selected to be 70 ppm or less and insulating layer 700 has a thickness of 40 μm or less. A suitable material for insulating layer 700 has a resolution capable of providing openings 702 or micro vias 706 with a diameter of 10 μm or less, thereby providing high-resolution electrical re-routing.

A conductive layer 720 is formed over insulating layer 700 and is electrically connected to conductive layer 277 of semiconductor die 276. A portion of conductive layer 720 extends

horizontally along insulating layer 700 and parallel to active surface 688 of semiconductor die 276 to laterally redistribute the electrical interconnect to conductive layer 277 of semiconductor die 276. Conductive layer 720 operates as a fan-out RDL, providing lateral or horizontal redistribution for the electrical signals of semiconductor die 276. Conductive layer 720 has a conductive micro via array 724 formed outside a footprint of semiconductor die 276. Conductive micro via array 724 includes one or more conductive micro vias 722. Conductive micro via array 724 extends from the horizontal portion of conductive layer 720 through insulating layer 700 to surface 692 of encapsulant 696. Insulating layer 734 is formed over insulating layer 700 and conductive layer 720. Insulating layer 734 includes openings 736 over conductive layer 720. In one embodiment, insulating layer 734 includes a reinforcement fiber or a woven fiber and has a resolution capable of providing openings 736 with a diameter of 30 μm or less. In an alternative embodiment, insulating layer 734 is a composite material including a prepreg material and a resin, such as epoxy-based resin, the resin enhanced with woven fiber, cloth, glass, or woven glass. The CTE for insulating layer 734 is selected to be 70 ppm or less. Insulating layer 734 has a thickness of 40 μm or less. Insulating layer 734 provides openings for electrical routing and provides physical support for the FO-WLCSP device. Conductive layer 740 is formed over insulating layer 734 and within openings 744 over conductive layer 720. Conductive layer 740 is electrically connected to conductive layer 720 and to conductive layer 277 of semiconductor die 276.

An insulating layer 742 is formed over conductive layer 740 and insulating layer 734. In one embodiment, insulating layer 742 is a composite material including a reinforcement fiber, filler, woven fiber, or woven glass. In an alternative embodiment, insulating layer 742 is a composite material including a prepreg material and a resin, such as epoxy-based resin, the resin enhanced with woven fiber, cloth, glass, or woven glass. The CTE for insulating layer 742 is selected to be 70 ppm or less and insulating layer 742 has a thickness of 40 μm or less. In one embodiment, insulating layer 742 includes a high glass transition temperature of over 260° C. Insulating layer 742 provides environmental protection and structural support for the FO-WLCSP device.

An insulating layer 764 is formed over backside surface 762 of encapsulant 696 and the back surface of semiconductor die 276. Insulating layer 764 operates as a backside protection and balancing layer, providing environmental protection for the semiconductor device from external elements and contaminants. Additionally, insulating layer 764 provides structural support for the package, to balance stress on the package, and reduce warping or cracking of the package during subsequent handling and processing.

A portion of encapsulant 696 and insulating layers 700 and 764 is removed over conductive micro via array 724 to form openings 770, which each constitute a through-mold-hole. In one embodiment, openings 770 have a sloped sidewall 774. Openings 770 expose conductive micro via array 724 and conductive micro vias 722 of conductive layer 720 through encapsulant 696. The exposed conductive micro via array 724 provides a greater exposed surface area for conductive layer 720 than would be exposed if the exposed conductive layer 720 were flat or planar. Conductive micro via array 724 thereby provides greater contact surface area between conductive layer 720 and subsequently deposited conductive bump material than if the exposed portion of conductive layer 720 were flat or planar. The additional exposed surface area of conductive layer 720, resulting from conductive micro via array 724, provides for improved and more robust electrical

and mechanical contact between subsequently deposited conductive bump material and conductive layer 720.

An electrically conductive bump material is deposited within openings 770 over conductive layer 720 to form bumps 776. Bumps 776 are formed over conductive layer 720 and over and between conductive micro vias 722 of conductive micro via array 724. Accordingly, a 3-D interconnection for next level interconnection is formed through bumps 776, conductive layer 720, conductive micro vias 722, build-up interconnect structure 752, and semiconductor die 276. The 3-D interconnection provides horizontal and vertical electrical interconnection for semiconductor die 276 without a backside interconnect or RDL over a footprint of semiconductor die 276. Conductive micro vias 722 and conductive micro via array 724 provide an increased contact surface area and improved and more robust mechanical and electrical connection between conductive layer 720 and bumps 776. Therefore, FO-WLCSP 786 provides fan-out routing with vertical interconnection and multiple semiconductor die formed side-by-side within the device.

FIG. 28 illustrates an alternative embodiment of the 3-D FO-WLCSP including a vertical interconnect structure and an optically transmissible layer over the semiconductor die. FO-WLCSP 790 is formed by a process similar to the process shown in FIGS. 26a-26h and 26k-26o. In FIG. 28, semiconductor die 792 includes an active surface 794 which contains a sensor. Active surface 794 is responsive to an external stimulus such as light, sound, heat, electromagnetic radiation, electric fields, magnetic fields, motion, ionizing radiation, vibration, motion, acceleration, rotation, pressure, or temperature.

Insulating layer 796 is similar to insulation layer 278 and is formed over active surface 794 of semiconductor die 792. A portion of insulating layer 796 is removed from over a portion of contact pads 797. Insulating layer 796 passes the external stimulus, e.g., sound, electromagnetic radiation, electric field, magnetic field, ionizing radiation, vibration, motion, acceleration, rotation, orientation, pressure, and temperature, to active surface 794. In one embodiment, insulating layer 796 is an optically transparent or translucent dielectric material for passing light to active surface 794. Insulating layer 796 is optically transmissible and does not block light or other signals from being transmitted to active surface 794 of semiconductor die 792.

Encapsulant 798 is similar to encapsulant 696 and is deposited over and around semiconductor die 792 and over a carrier. After encapsulant 798 is deposited, the carrier is removed. Insulating layer 800 is similar to insulating layer 700 and is formed over encapsulant 798 and over semiconductor die 792. Insulating layer 800 passes the external stimulus, e.g., sound, electromagnetic radiation, electric field, magnetic field, ionizing radiation, vibration, motion, acceleration, rotation, orientation, pressure, and temperature, to active surface 794. In one embodiment, insulating layer 800 is an optically transparent or translucent dielectric material for passing light to active surface 794. Insulating layer 800 is optically transmissible and does not block light or other signals from being transmitted to active surface 794 of semiconductor die 792.

Openings or micro vias are formed in insulating layer 800 and are similar to openings 702 and micro vias 706. Conductive layer 802 is similar to conductive layer 720 and is formed over insulating layer 800 and within the micro vias to form conductive micro vias 804 which are similar to conductive micro vias 722. Conductive micro vias 804 form a micro via array similar to conductive micro via array 724 outside a footprint of semiconductor die 792. Conductive layer 802 is

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electrically connected to semiconductor die 792 and operates as a fan-out RDL, providing lateral or horizontal redistribution for the electrical signals of semiconductor die 792. Conductive layer 802 is not formed over the sensor, which is within active surface 796 of semiconductor die 792. Conductive layer 802 is formed outside a footprint of the sensor such that conductive layer 802 does not block the sensor of semiconductor die 792. Alternatively, conductive layer 802 is formed over semiconductor die 792 and a portion of conductive layer 802 over the sensor is subsequently removed.

Insulating layer 806 is similar to insulating layer 734 and is formed over insulating layer 800 and over conductive layer 802. Insulating layer 806 is not formed over the sensor, which is within active surface 796 of semiconductor die 792. Insulating layer 806 is formed outside a footprint of the sensor such that insulating layer 806 does not block the sensor of semiconductor die 792. Alternatively, insulating layer 806 is formed over semiconductor die 792 and openings 808 are formed in insulating layer 806 over the sensor, which is within active surface 796 of semiconductor die 792. Openings 808 are formed by removing a portion of insulating layer 806 by LDA, by an etching process with a patterned photoresist, developing with a chemical process, or other suitable process. Insulating layers 800 and 806 and conductive layer 802 with conductive micro vias 804 together constitute a build-up interconnect structure 812.

Encapsulant 798 undergoes a grinding operation to planarize and reduce a thickness of encapsulant 696. A back grinding tape, similar to back grinding tape 754, may be applied over build-up interconnect structure 812 prior to back grinding encapsulant 798. The back grinding tape is subsequently removed. Insulating layer 810 is similar to insulating layer 764 and is formed over exposed backside surface 814 of encapsulant 798 and a back surface of semiconductor die 792. Insulating layer 810 operates as a backside protection and balancing layer, providing environmental protection for the semiconductor device from external elements and contaminants. Additionally, insulating layer 810 provides structural support for the package, to balance stress on the package, and reduce warping or cracking of the package during subsequent handling and processing.

A portion of encapsulant 798 and insulating layer 810 is removed in a peripheral region of semiconductor die 792 over conductive micro vias 804 to form openings 816 similar to openings 770. Openings 816 may include sloped sidewalls have a first diameter or cross-sectional width within openings 816 ranging from 50-150 μm , and a second diameter or cross-sectional width within openings 816, ranging from 180-450 μm . The process of forming openings 816 further includes removing a portion of insulating layer 800 covering conductive micro vias 804 to expose conductive micro vias 804. The exposed conductive micro via array including conductive micro vias 804 provides a greater exposed surface area for conductive layer 802 than would be exposed if the exposed conductive layer 802 were flat or planar. The conductive micro via array thereby provides greater contact surface area between conductive layer 802 and subsequently deposited conductive bump material than if the exposed portion of conductive layer 802 were flat or planar. The additional exposed surface area of conductive layer 802, resulting from conductive micro via 804, provides for improved and more robust electrical and mechanical contact between subsequently deposited conductive bump material and conductive layer 802.

An electrically conductive bump material is deposited within openings 816 over conductive layer 802 to form bumps 818. Bumps 818 are formed over conductive layer 802 and

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over and between conductive micro vias 804 of the conductive micro via array. Accordingly, a 3-D interconnection for next level interconnection is formed through bumps 818, conductive layer 802, build-up interconnect structure 812, and semiconductor die 792. The 3-D interconnection provides horizontal and vertical electrical interconnection for semiconductor die 792 without a backside interconnect or RDL over a footprint of semiconductor die 792. Conductive micro vias 804 provide an increased contact surface area and improved and more robust mechanical and electrical connection between conductive layer 802 and bumps 818.

FO-WLCSP 790 including optically transmissible insulating layers allows the light-sensitive active surface 794 of semiconductor die 792 to respond to an optical source, for example, to sense and detect motion, images, light radiation, and pressure. Forming the fan-out redistribution layer over active surface 794 of semiconductor die 792 provides a lower profile than conventional optically-sensitive semiconductor packages that employ the use of leadframes or laminate-based substrates, and allows for a more cost-effective manufacturing process. Therefore, FO-WLCSP 790 incorporates a sensor device into a 3-D FO-WLCSP including a vertical interconnect structure.

FIG. 29 illustrates another embodiment of the 3-D FO-WLCSP including a vertical interconnect structure and an embedded PCB. FO-WLCSP 830 is formed by a process similar to the process shown in FIGS. 26a-26f, but with semiconductor die 276 and a PCB 832 embedded within encapsulant. Insulation layer 278 is formed over active surface 688 of semiconductor die 276. A portion of insulation layer 278 is removed from over a portion of contact pads 277. Semiconductor die 276 is mounted over a carrier, not shown in FIG. 29, and PCB 832 is mounted adjacent to semiconductor die 276 over the carrier.

PCB 832 includes one or more laminated layers of prepreg, FR-4, FR-1, CEM-1, or CEM-3 with a combination of phenolic cotton paper, epoxy, resin, woven glass, matte glass, polyester, and other reinforcement fibers or fabrics. Alternatively, PCB 832 may include a substrate containing one or more laminated insulating or dielectric layers. In another embodiment, PCB 832 contains base material, such as silicon, germanium, gallium arsenide, indium phosphide, or silicon carbide, for structural support. PCB 832 can also be a multi-layer flexible laminate, ceramic, or leadframe. PCB 832 may include modular PCB units formed from PCB panels.

PCB 832 may include conductive pillars or conductive vias 834. A plurality of vias is formed through a substrate of PCB 832 using laser drilling, mechanical drilling, or DRIE. The vias are filled with Al, Cu, Sn, Ni, Au, Ag, Ti, W, poly-silicon, or other suitable electrically conductive material using electrolytic plating, electroless plating process, or other suitable metal deposition process to form z-direction vertical interconnect conductive vias 834.

PCB 832 includes insulating layers and RDLs formed over one or both surfaces of PCB 832. An electrically conductive layer or RDL 836 is formed over a first surface of the substrate of PCB 832 and conductive vias 834 using a patterning and metal deposition process such as printing, PVD, CVD, sputtering, electrolytic plating and electroless plating. Conductive layer 836 includes one or more layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable electrically conductive material. Conductive layer 836 is electrically connected to conductive vias 834.

An insulating or passivation layer 838 is formed over PCB 832 and conductive layer 836 using PVD, CVD, printing, spin coating, spray coating, sintering or thermal oxidation. The

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insulating layer **838** contains one or more layers of SiO₂, Si₃N₄, SiOn, Ta₂O₅, Al₂O₃, or other material having similar insulating and structural properties. A portion of insulating layer **838** is removed by LDA, by an etching process with a patterned photoresist layer, developing with a chemical process, or other suitable process to form openings and expose conductive layer **836**.

An electrically conductive layer or RDL **840** is formed over a first surface of the substrate of PCB **832**, over insulating layer **838**, and within openings of insulating layer **838** over conductive layer **836** using a patterning and metal deposition process such as printing, PVD, CVD, sputtering, electrolytic plating and electroless plating. Conductive layer **840** includes one or more layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable electrically conductive material. Conductive layer **840** is electrically connected to conductive layer **836** and to conductive vias **834**. Layers of insulating and conductive material over PCB **832** allow for electrical re-routing over a first surface of PCB **832**.

An electrically conductive layer or RDL **842** is formed over a second surface of PCB **832** opposite the first surface and over conductive vias **834** using a patterning and metal deposition process such as printing, PVD, CVD, sputtering, electrolytic plating and electroless plating. Conductive layer **842** includes one or more layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable electrically conductive material. Conductive layer **842** is electrically connected to conductive vias **834**.

An insulating or passivation layer **844** is formed over PCB **832** and conductive layer **842** using PVD, CVD, printing, spin coating, spray coating, sintering or thermal oxidation. The insulating layer **844** contains one or more layers of SiO₂, Si₃N₄, SiOn, Ta₂O₅, Al₂O₃, or other material having similar insulating and structural properties. A portion of insulating layer **844** is removed by LDA, by an etching process with a patterned photoresist layer, developing with a chemical process, or other suitable process to form openings and expose conductive layer **842**.

An electrically conductive layer or RDL **846** is formed over a first surface the substrate of PCB **832**, over insulating layer **844**, and within openings of insulating layer **844** over conductive layer **842** using a patterning and metal deposition process such as printing, PVD, CVD, sputtering, electrolytic plating and electroless plating. Conductive layer **846** includes one or more layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable electrically conductive material. Conductive layer **846** is electrically connected to conductive layer **842**. Layers of insulating and conductive material over PCB **832** allow for electrical re-routing over a second surface of PCB **832**.

The resulting PCB **832** provides electrical interconnect vertically and laterally across PCB **832** through conductive layers **836**, **840**, **842**, **846** and conductive vias **834** according to the electrical function of PCB **832**. Portions of conductive layers **836**, **840**, **842**, **846** and conductive vias **834** are electrically common or electrically isolated according to the design and function of PCB **832**.

Encapsulant **696** is deposited over and around semiconductor die **276** and PCB **832** and over a carrier. A portion of encapsulant **696** over semiconductor die **276** and PCB **832** may be removed to expose a backside surface of semiconductor die **276** and PCB **832** and surface **762** of encapsulant **696**. After encapsulant **696** is deposited, the carrier is removed. A build-up interconnect structure **752** is formed over active surface **688** of semiconductor die **276**. Prior to forming build-up interconnect structure **752**, an insulating layer **764** is formed over exposed backside surface **762** of encapsulant **696** and a back surface of semiconductor die **276**. Insulating layer **764** operates as a backside protection and balancing

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layer, providing environmental protection for the semiconductor device from external elements and contaminants. Additionally, insulating layer **764** provides structural support for the package, to balance stress on the package, and reduce warping or cracking of the package during subsequent handling and processing.

Insulating layer **700** is formed over encapsulant **696**, PCB **832**, and semiconductor die **276**. In one embodiment, insulating layer **700** is a composite material including reinforcement fiber, filler, woven fiber, or woven glass. In an alternative embodiment, insulating layer **700** is a composite material including a prepreg material and a resin, such as epoxy-based resin, the resin enhanced with woven fiber, cloth, glass, or woven glass. The CTE for insulating layer **700** is selected to be 70 ppm or less and insulating layer **700** has a thickness of 40 μm or less. Openings **702** and micro vias **706** are formed in insulating layer **700**. A suitable material for insulating layer **700** has a resolution capable of providing openings **702** or micro vias **706** with a diameter of 10 μm or less, thereby providing high-resolution electrical re-routing.

Conductive layer **720** is formed over insulating layer **700** and within the micro vias to form conductive micro vias **722**. Conductive micro vias **722** form conductive micro via array **724** outside a footprint of semiconductor die **276**. Conductive layer **720** is electrically connected to semiconductor die **276** and operates as a fan-out RDL, providing lateral or horizontal redistribution for the electrical signals of semiconductor die **276**. Insulating layer **734** is formed over insulating layer **700** and over conductive layer **720**. Openings are formed in insulating layer **734** by removing a portion of insulating layer **734** by LDA, by an etching process with a patterned photoresist, developing with a chemical process, or other suitable process. The CTE for insulating layer **734** is selected to be 70 ppm or less and insulating layer **734** has a thickness of 40 μm or less. In one embodiment, insulating layer **734** is a similar material as insulating layer **700**. In another embodiment, insulating layer **734** is a composite material including polymer and a reinforcement fiber, filler, woven fiber, or woven glass. In yet another embodiment, insulating layer **734** is a composite material including a prepreg material and a resin, such as epoxy-based resin, the resin enhanced with woven fiber, cloth, glass, or woven glass.

Conductive layer **740** is formed over insulating layer **734** and within openings in insulating layer **734** over conductive layer **720**. Conductive layer **740** is electrically connected to conductive layer **720** and to conductive layer **277** of semiconductor die **276**. An insulating layer **742** is formed over conductive layer **740** and insulating layer **734**. In one embodiment, insulating layer **742** is the same material as insulating layer **734** and insulating layer **700**. In another embodiment, insulating layer **742** is a composite material including polymer and a reinforcement fiber, filler, woven fiber, or woven glass. In yet another embodiment, insulating layer **742** is a composite material including a prepreg material and a resin, such as epoxy-based resin, the resin enhanced with woven fiber, cloth, glass, or woven glass. The CTE for insulating layer **742** is selected to be 70 ppm or less and insulating layer **742** has a thickness of 40 μm or less. In one embodiment, insulating layer **742** includes a high glass transition temperature of over 260° C. Insulating layer **742** provides environmental protection and structural support for the FO-WLCSP device.

An electrically conductive bump material is deposited over the exposed conductive layer **740** to form bumps **750**. A UBM layer can be formed under bumps **750**. Bumps **750** can also be compression bonded to conductive layer **740**. Bumps **750** represent one type of conductive interconnect structure that

can be formed over conductive layer 740. The interconnect structure can also use stud bump, micro bump, or other electrical interconnect.

Collectively, insulating layers 700, 734, and 742, conductive layers 720 and 740, and bumps 750 constitute a build-up interconnect structure 752 formed over semiconductor die 276 and encapsulant 696 with conductive micro via array 724 formed outside a footprint of semiconductor die 276. Build-up interconnect structure 752 may include as few as one RDL or conductive layer, such as conductive layer 720. Additional insulating layers and RDLs can be formed over insulating layer 742 prior to forming bumps 750, to provide additional vertical and horizontal electrical connectivity across the package according to the design and functionality of semiconductor die 276.

Insulating layer 764 can be partially or completely removed by mechanical grinding, by LDA, or by another suitable process after the formation of build-up interconnect structure 752 to expose a back surface of semiconductor die 276 and a backside surface 762 of encapsulant 694. Alternatively, insulating layer 764 is not removed and remains over a back surface of semiconductor die 276 and a backside surface 762 of encapsulant 694.

FO-WLCSP 830 provides 3-D electrical interconnection with a fan-out RDL, embedded PCB, and a conductive micro via array formed outside a footprint of a semiconductor die 276. Conductive micro vias 722 provide a greater surface area for conductive layer 720 than would be exposed if the exposed conductive layer 720 were flat or planar. Embedded PCB 832 provides a vertical interconnect structure and can be made with low cost manufacturing technology such as substrate manufacturing technology rather than laser drilling. PCB 832 contain a single row or multiple rows of vertical interconnect structures or conductive vias 834, which provide through vertical interconnection between opposing sides of PCB 832. PCB 832 may also include additional metal layers to facilitate design integration and increased routing flexibility before build-up interconnect structure 752 is formed over PCB 832. FO-WLCSP 830 provides build-up interconnect structure 752 over active surface 688 of semiconductor die 276 which is electrically connected to PCB 832 through the RDL layers, such as conductive layers 836 and 840, formed over PCB 832 and conductive layers 720 and 740. The insulating and conductive layers of build-up interconnect structure 752 can be selected and formed according to the electrical routing and structural requirements for the semiconductor device. Insulating layers 700, 734, and 742 can each be similar materials. Alternatively, insulating layer 742 is selected to have a filler to increase the hardness of insulating layer 742 and to reduce the CTE of insulating layer 742.

FIG. 30 illustrates a stacked 3-D FO-WLCSP with vertical interconnect structure to electrically connect the stacked 3-D FO-WLCSP. A bump or other suitable conductive material is formed in the through-mold-holes to form 3D vertical interconnects for next level interconnection and POP configurations. An electrically conductive bump material is deposited over the exposed conductive layer 720 and conductive micro vias 722 using an evaporation, electrolytic plating, electroless plating, ball drop, or screen printing process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to conductive layer 720 using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form balls or bumps 776. In some applications, bumps 776 are reflowed a second

time to improve electrical contact to conductive layer 720. A UBM layer can be formed under bumps 776. Bumps 776 can also be compression bonded to conductive layer 720. Bumps 776 represent one type of conductive interconnect structure that can be formed over conductive layer 720.

Semiconductor devices are stacked with a back surface of a FO-WLCSP device oriented toward the back surface of another FO-WLCSP device to form a POP or stacked FO-WLCSP 850. FO-WLCSP 790 is mounted over FO-WLCSP 782 back-to-back to merge and form stacked FO-WLCSP 850. Bumps 776 of FO-WLCSP 790 and bumps 776 FO-WLCSP 782 are reflowed to merge and form a single bump 776 electrically connected to FO-WLCSP 790 and FO-WLCSP 782. Bumps 776 are electrically connected to conductive layer 720 and conductive micro vias 722 of FO-WLCSP 782. Bumps 776 are electrically connected to conductive layer 802 and conductive micro vias 804 of FO-WLCSP 790. Therefore, bumps 776 electrically connect FO-WLCSP 790 and FO-WLCSP 782. Alternatively, FO-WLCSP 790 is electrically connected to FO-WLCSP 782 through a vertical interconnect structure, such as a conductive pillar, conductive post, or conductive via. Stacked FO-WLCSP 850 can be mounted to and electrically connected to additional devices through bumps 750. Stacked FO-WLCSP 850 includes semiconductor die 792 with active surface 794 oriented outwards relative to the POP structure in order to receive external stimulus. Semiconductor die 792 including a sensor is embedded in 3-D stacked FO-WLCSP 850. Stacked FO-WLCSP 850 provides active surface 794 of semiconductor die 792 oriented in a direction opposite to FO-WLCSP 782 in order to receive external stimuli.

FIG. 31 illustrates another stacked 3-D FO-WLCSP with vertical interconnect structure to electrically connect the stacked 3-D FO-WLCSP. FO-WLCSP 786 is mounted over FO-WLCSP 782 back-to-back to form stacked FO-WLCSP 860. Within stacked FO-WLCSP 860, FO-WLCSP 786 is electrically connected to FO-WLCSP 782 through a vertical interconnect structure formed outside a footprint of semiconductor die 276. In one embodiment, the vertical interconnect structure includes a bump material reflowed by heating the material above its melting point to form balls or bumps 776 electrically connecting the stacked FO-WLCSP devices. Bumps 776 are electrically connected to conductive layer 720 and conductive micro vias 722 of FO-WLCSP 782. Bumps 776 are electrically connected to conductive layer 720 and conductive micro vias 722 of FO-WLCSP 786. Therefore, bumps 776 electrically connect FO-WLCSP 786 and FO-WLCSP 782. Alternatively, FO-WLCSP 786 is electrically connected to FO-WLCSP 782 through a vertical interconnect structure, such as a conductive pillar, conductive post, or conductive via. Stacked FO-WLCSP 860 can be mounted to and electrically connected to additional devices through bumps 750. FO-WLCSP 786 includes a plurality of semiconductor die 276 embedded within FO-WLCSP 786.

FIG. 32 illustrates another stacked 3-D FO-WLCSP with a vertical interconnect structure to electrically connect the stacked 3-D FO-WLCSP. Stacked FO-WLCSP 870 includes a FO-WLCSP similar to FO-WLCSP 790 but including two semiconductor die mounted side-by-side. The top FO-WLCSP is mounted with a backside oriented towards a bottom FO-WLCSP, which is similar to FO-WLCSP 782, thereby forming stacked FO-WLCSP 870. Within stacked FO-WLCSP 870, the individual FO-WLCSP devices are electrically connected through a vertical interconnect structure formed outside a footprint of semiconductor die 276 and 792. In one embodiment, the vertical interconnect structure includes a bump material reflowed by heating the material

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above its melting point to form balls or bumps **776** electrically connecting the stacked FO-WLCSP devices. Bumps **776** are electrically connected to conductive layer **720** and conductive micro vias **722** and to conductive layer **802** and conductive micro vias **804**. Therefore, bumps **776** electrically connect each FO-WLCSP to form stacked FO-WLCSP **870**. Alternatively, the FO-WLCSP devices are electrically connected to FO-WLCSP **782** through a vertical interconnect structure, such as a conductive pillar, conductive post, or conductive via. Stacked FO-WLCSP **870** can be mounted to and electrically connected to additional devices through bumps **750**. Stacked FO-WLCSP **870** includes a plurality of semiconductor die **792** with active surface **794** oriented outwards relative to the POP structure in order to receive external stimulus. Multiple semiconductor die **792** including a sensor are embedded in 3-D stacked FO-WLCSP **870**. Stacked FO-WLCSP **870** provides active surfaces **794** of semiconductor die **792** oriented in an outward direction to receive external stimuli.

While one or more embodiments of the present invention have been illustrated in detail, the skilled artisan will appreciate that modifications and adaptations to those embodiments may be made without departing from the scope of the present invention as set forth in the following claims.

What is claimed:

1. A semiconductor device, comprising:
 - a semiconductor die;
 - a conductive layer formed over the semiconductor die;
 - an encapsulant deposited around the semiconductor die;
 - a first insulating layer formed over a surface of the semiconductor die opposite the conductive layer; and
 - an interconnect structure formed through the encapsulant and first insulating layer outside a footprint of the semiconductor die.
2. The semiconductor device of claim 1, further including a second insulating layer formed over the semiconductor die, wherein the second insulating layer includes an optically transparent or translucent material.

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3. The semiconductor device of claim 1, wherein the interconnect structure further includes:

- an opening formed through the encapsulant over the conductive layer; and
- a conductive material deposited in the opening electrically connected to the conductive layer.

4. The semiconductor device of claim 1, further including a conductive via formed through the first insulating layer outside the footprint of the semiconductor die.

5. The semiconductor device of claim 1, further including a plurality of stacked semiconductor devices electrically connected through the interconnect structure.

6. A semiconductor device, comprising:

- a semiconductor die;
- a conductive layer formed over the semiconductor die;
- a first insulating layer formed over the semiconductor die; and
- an interconnect structure formed outside a footprint of the semiconductor die through the first insulating layer and electrically connected to the conductive layer.

7. The semiconductor device of claim 6, further including an encapsulant deposited over and around the semiconductor die and the interconnect structure.

8. The semiconductor device of claim 6, further including a second insulating layer formed over the conductive layer.

9. The semiconductor device of claim 6, wherein the interconnect structure includes a printed circuit board.

10. The semiconductor device of claim 8, wherein the second insulating layer includes an optically transparent or translucent material.

11. The semiconductor device of claim 8, wherein the semiconductor die further includes a sensor configured to receive an external stimulus passing through the second insulating layer.

12. The semiconductor device of claim 6, further including a plurality of stacked semiconductor devices electrically connected through the interconnect structure.

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